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(71) Applicant *(for all designated States except US):* BICC NETWORK SOLUTIONS, INC. [US/US]; 103 Millbury Street, Auburn, MA 01501 (US).

(71)(72) Applicants and Inventors: OLMSTEAD, Charles [US/US]; 111 Country Club Blvd., Worcester, MA 01605 (US). HICKS, John, Wilbur [US/US]; 312 Howard Street, Northborough, MA 01532 (US). MOORE, Wayne [US/US]; 312 Main Street, Marlboro, MA 01752 (US). BURDICK, Dominic [US/US]; 16 Mead Street, Allston, MA 02134 (US). MANSFIELD, Robert [US/US]; 69 Packard Road, Stow, MA 01775 (US).

(74) Agent: PASQUALE, Jack, M.; McCormick, Paulding & Huber, 266 Pearl Street, Hartford, CT 06103 (US).

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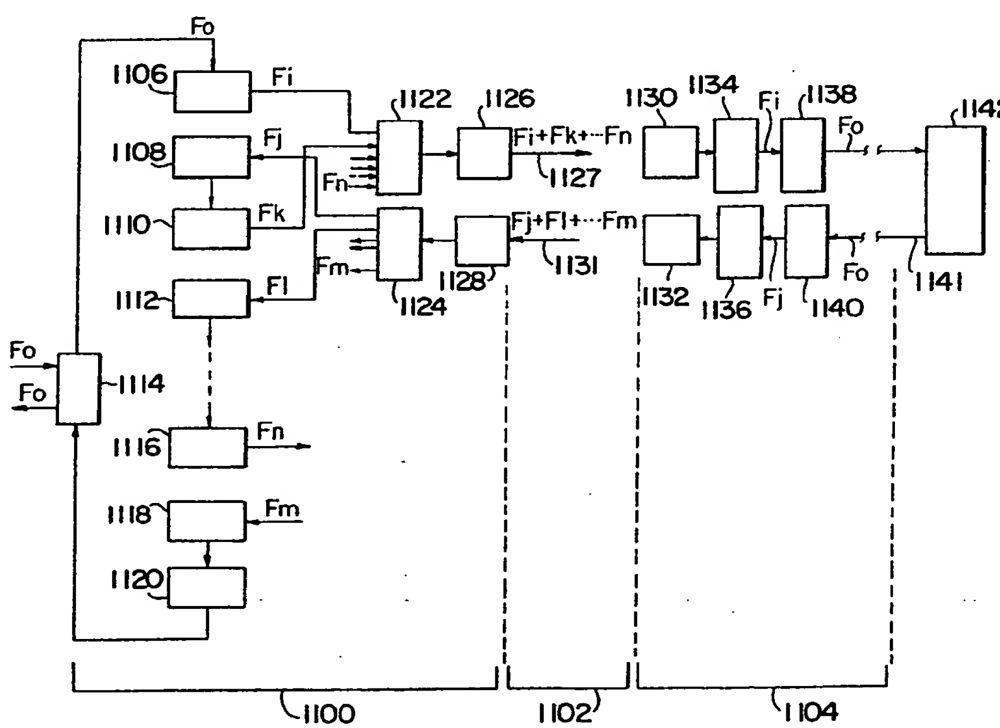
(57) Abstract

In a local area network the conventional "hard wire" connection between a data communication device (142) and a network segment is replaced with a pair of transmitter/receiver units (1130/1132, 1126/1131) which communicate optically through free space (1102). The optical connections can be configured to conform to a variety of conventional protocols including carrier sense multiple access/collision detect and token passing ring protocols. The transmitter/receiver units can communicate with each other by means of coded control signals which are not passed along the network. In this manner, the optical link is managed directly by the transmitter/receiver units and many of the problems, such as collision detection and failed link removal, which have plagued the prior art are avoided without involving the network.



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FREE SPACE LOCAL AREA NETWORK SYSTEM

FIELD OF THE INVENTION

This invention relates to data communication systems and, more specifically, to local area network data communication systems.

BACKGROUND OF THE INVENTION

The proliferation of data communication devices, such as computers and video display units throughout offices, laboratories and workplaces has fostered the installation of data communication networks between these devices to allow them to exchange data. These communication networks, generally called local area networks, or LANs, are comprised of a number of distinct sections or segments. In a typical LAN, several data communication devices are connected to a local segment. Several local segments are, in turn, connected to a central segment, called a backbone, by means of repeaters and bridges.

A problem with conventional LANs is that the electrical connection between a data communication device and its LAN local segment is typically made by means of cables or wires. Consequently, when the physical location of the device is changed or when devices are added, the wiring must be modified. At present, the installation and modification of the LAN physical wiring represents a large portion of the cost of a LAN and it is not uncommon for the cost of the wiring modifications to exceed the original LAN installation cost within a few years.

Consequently, the prior art has sought to eliminate the physical wiring between the data communication devices and their associated LAN segments by means of nonphysical connections such as radio or optical links. In such an arrangement both the data communication devices and the network use transmitter/receiver units to send information back and forth by means of light pulses or radio carrier frequencies. Several

prior art attempts have been made to design systems using the latter modes of transmission.

However, experience has shown that radio waves have significant limitations when used to convey high bit-rate data signals in buildings. In addition, radiating transmitters generally require certification by regulatory agencies such as the F.C.C. Due to these considerations, radio waves are generally not used to link communication devices to a network.

Several prior art systems have used optical links with either fiber optic transmission or by transmitting directly across free space. While the optical fibers are less expensive to maintain than wires, they still require significant overhead to install and maintain. Free space transmission frees the data communication devices from physical connection to the LAN network and thus reduces maintenance costs but has encountered other problems.

More particularly, transmission across free space requires relatively powerful transmission sources such as semiconductor lasers. When such lasers are used in an inhabited space, the light produced by the lasers may harm the eyes of persons who look directly at the transmitter in the line of transmission. Further, in such systems there are problems with "collision" detection.

Specifically, there are several types of LAN configurations commonly in use. These configurations have evolved to eliminate or handle "collisions". A "collision" occurs when two different data communication devices attempt to transmit on the network simultaneously. Since a network can reliably handle only a single transmission, it must have some mechanism for arbitrating use. Each conventional network configuration has a mechanism for either preventing a collision from occurring or dealing with a collision when it does occur. Well-known network configurations are governed by a set of standards or protocols. One such protocol is IEEE Standard 802.3. This

protocol defines a network in which several communication devices are connected to a single segment and transmit over the segment at arbitrary times. Collisions are detected and use of the bus is arbitrated by a bus controller.

Another popular protocol is IEEE Standard 802.4 which defines a network in which several communication devices are connected to a single segment. However, the devices cannot transmit over the segment at arbitrary times. Instead, a device may only transmit when it receives a "token" or special data word from the segment. Since only a single device may have the token at any given time, collisions are eliminated.

Still another protocol is IEEE Standard 802.5 which defines a network in which the data communication devices are connected in a ring configuration. As in the previously-mentioned protocol, a "token" is passed from device to device in the ring to control access to the network.

In addition, some vendors of networks and data communication devices have developed their own proprietary protocols for use with their systems.

In order to detect collisions in those networks which require collision detection (such as IEEE Standard 802.3), the prior art has developed several detection methods which work well when data communication devices are connected to the network by wires but have severe limitations when the devices are connected by free space optical links. For example, if a coaxial cable is used to connect data communication devices to the network, collisions can be easily detected in accordance with conventional designs by monitoring the voltage level in the cable. A collision causes unusually high voltage levels on the cable. This high voltage level results from the fact that each device transmits a signal on the network at a uniform and well-defined voltage level. Therefore, when two or more devices transmit at the same time, the voltage level produced

by each device adds to the voltage levels produced by other devices causing the overall level to exceed a predefined level.

In the case of optical transmission systems, prior art techniques for optical collision detection have generally relied upon one of two methods: average power monitoring and code violations. The former method is similar to the collision detection method used in coaxial cable in that the average received optical power is monitored and a threshold level is established. If the monitored signal level exceeds the threshold level, a collision is assumed. However, in a free space optical transmission system, the problem of collision detection is more complicated, since the signal strength from each transmitter may vary according to the distance of the transmitter from the receiver, the age and efficiency of the transmitting element, and the physical alignment of the optical components. Due to these factors, such a system requires very careful control of the optical transmitters and there are severe limitations on the transmission distance.

In the case of the code violation method, the duty cycle of the received signal is monitored to detect the presence of any unusually long or short data pulses which would be expected to occur if transmissions from two or more devices overlapped. However, this latter technique may only be used when the transmitted signal has well-defined pulse widths and duty cycles (as in the case of Manchester encoded signals). Furthermore, if two such signals were to be transmitted at exactly the same time, the resulting composite signal would contain no unusually long or short pulses and the collision would not be detected. In addition, in an optical link system, the signal strength from the various transmitting elements may vary by such an extent that one large amplitude signal may dominate and swamp signals of smaller amplitudes. It therefore becomes very difficult for weaker transmitters to communicate in the event of a collision.

Consequently, it is an object of this invention to provide a reliable, low-cost local area network in which data communication devices are connected to the network by receiver/transmitter units which operate over free space.

It is another object of this invention to provide a reliable, low-cost local area network that does not require special skills or tools to install or to maintain.

It is a further object of this invention to provide a reliable, low-cost local area network which can accommodate any conventional operational protocols depending on the connections.

It is still a further object of this invention to provide a reliable, low-cost local area network in which data communication devices are connected to the network by receiver/transmitter units which operate over free space and which can operate with a protocol that requires collision detection.

It is another object of this invention to provide a reliable, low-cost local area network in which data is transmitted by light pulses generated by light sources that pose no threat to the safety or health of nearby persons.

It is still another object of this invention to provide a reliable, low-cost local area network in which the optical components operate in such a manner that some deviation from a line-of-sight path between transmitters and receivers is permitted.

It is a further objective to provide a reliable, low-cost local area network in which optical links between data communication devices and the network function as a security system for detecting intrusions.

SUMMARY OF THE PRESENT INVENTION

The foregoing problems are solved and the foregoing objects are achieved in illustrative embodiments of the invention in which the conventional "hard wire" connection between a data communication device and a local network segment is replaced with a pair of transmitter/receiver units which communicate optically through free space. The transmitter/receiver units communicate with each other by means of coded control signals which are not passed along the network. In this manner, the optical link is managed directly by the transmitter/receiver units and many of the problems, such as collision detection and failed link removal, which have plagued the prior art are avoided without involving the network.

In accordance with one aspect of the invention, the pulses of light which are used to communicate between LAN segments and data communication devices are generated by lasers that transmit light pulses through an optical system using light source which diffuses the light so that the apparent brightness is reduced and the energy is radiated uniformly. Consequently, the light source is safe to the eyes of nearby persons even if they should look directly the source.

More particularly, a transmitter/receiver unit called a "sun" is connected to a local network and converts electronic signals on the network to light pulses that are transmitted in a specific direction. One or more additional transmitter/receivers called "satellites" gather a portion of the light generated by the sun and convert the light pulses to electronic signals which are conveyed to associated data communication devices. Each satellite also converts electronic signals generated by its associated data communication device to light pulses that are directed towards the sun to establish two-way communication between the sun and each of its satellites.

For those networks which require collision detection, the inventive network continuously controls average signal power on the optical link between a sun and its satellites. In order to monitor average power levels the sun, at the beginning of a communication session, measures the optical power received from a satellite. The sun then inserts a code when it knows that only one satellite has transmitted indicating the received power level in a transmission back to the satellite. Upon receiving the code, the satellite adjusts its transmitter power to maintain its transmission power at a predetermined level. Consequently, if a collision occurs and two or more satellites of the same sun transmit simultaneously with the same optical wavelength, the output of the combined signals as received by the sun will be greater than the output of one signal and the collision is detected.

For those networks requiring failed link removal, the communication between the sun and its satellites can be used to detect a failed link and automatically remove it from the network. For example, a sun is designed to emit a light pulse signal or "heartbeat" at predetermined time intervals when it is not otherwise transmitting. A satellite generates an audio or visible indication and also sends a special signal to its associated data communication device if it does not receive the light pulse signal at least once during the predetermined time interval, thus indicating to an operator that its link to a sun has become impaired.

A further aspect of the invention concerns an improved light source which utilizes an array of LEDs arranged in a focal ring about a reflecting apparatus which focuses the light in a narrow beam in a horizontal plane to transmit the light in a 360° direction.

Further, a sun has means to remove an impaired link from a network and maintain continuity of the network.

BRIEF DESCRIPTION OF THE DRAWING

Additional objects, features and advantages of the present invention will be readily apparent from the following written description of exemplary embodiments and the drawings wherein:

Fig. 1 is a block schematic diagram of a conventional LAN network showing the inventive optical system in the dotted box attached to the LAN network.

Fig. 2 is a physical side view of an illustrative LAN system using the sun/satellite arrangement of the present invention.

Fig. 3 is a physical plan view of another illustrative LAN system using the sun/satellite arrangement of the present invention.

Fig. 4 is an electrical block schematic diagram of an illustrative satellite embodiment.

Fig. 5 is an electrical block schematic diagram of an illustrative sun embodiment.

Fig. 6 is an electrical block schematic diagram of an optical collision detection circuit for use in the sun shown in Fig. 5.

Fig. 7 is an electrical waveform diagram which represents electrical waveforms processed by the circuitry disclosed in Fig. 6.

Fig. 8 is an electrical block schematic diagram of an illustrative embodiment of the invention arranged as a token passing ring LAN.

Fig. 9 is a block diagram which illustrates a physical sun and satellite placement which could result in crosstalk between elements.

Fig. 10 is a graph of amplitude versus frequency showing various frequency bands used in a multi-channel token passing ring optical LAN.

Fig. 11 is an electrical schematic block diagram of a multi-channel token passing ring optical LAN.

Fig. 12 is an electrical/physical schematic diagram of a sectored sum.

Fig. 13 is an electrical schematic block diagram of an illustrative sun for use in a token passing ring LAN in which the sun can automatically short circuit an impaired optical link.

Fig. 14 is an electrical schematic diagram of a switchable network which can be configured as either a CSMA/CD LAN network or as a token ring network.

Fig. 15A is an elevation view of an illustrative optical system for use with a sun element.

Fig. 15B is a perspective view of an illustrative sun element using the optical system of Fig. 15.

Fig. 15C is a schematic illustrative of the construction of the parabolic reflector surface.

Fig. 16 is an elevation view of an alternative optical system for a sun element which optical system is advantageous for use with network that requires separate optical channels between a sun and each of its satellites.

Fig. 17 is a plan view of the optical system of Fig. 16 taken in the direction of arrows 17-17 in Fig. 16.

Fig. 18 is an elevation view of another illustrative optical system for use with a sun element.

Fig. 19 is an elevation view of an illustrative optical system for use with a satellite element.

Fig. 19A is a perspective view of an illustrative satellite element using the optical system of Fig. 19.

Fig. 20A is a perspective view of a reflector element of the optical system shown in Fig. 19.

Fig. 20B is a top view of the reflector/detector system of Fig. 20A using a planar reflector.

Fig. 20C is a top view of the reflector/detector system of Fig. 20A using a circular reflector.

Fig. 20D is a side view of the reflector/detector system of Fig. 20A showing the parabolic shape in the vertical direction.

Fig. 20E is a perspective view of the reflector element of Fig. 20A arranged for multiple channel capability.

Fig. 21 is an elevation view of another illustrative optical system for use with a satellite element.

Fig. 22 is an elevation view of another illustrative optical system for use with a satellite element.

Fig. 23 is an elevation view of another illustrative optical system for use with both sun and satellite elements.

Fig. 24 is an embodiment of a light source in which the effective emitting area has been increased so that eye damage can be eliminated.

Fig. 25 is another embodiment of a light source in which the effective emitting area has been increased so that eye damage can be eliminated.

Fig. 25A is still another embodiment of a light source in which the effective emitting area has been increased so that eye damage can be eliminated.

Fig. 26 illustrates schematically a cross section view of a typical light emitting diode (LED).

Fig. 27 is a graphic representation of the light output intensity from a LED as a function of the angle of the emitted light ray.

Fig. 28 is a schematic top plan view of another embodiment of a light source utilizing an array of LED's and reflecting surface to transmit light in a 360° direction.

Fig. 29 is a schematic cross section view along the line 29-29 of Fig. 28.

Fig. 30 is a schematic diagram of an arrangement for aligning the line-of-sight path between a sun and a satellite.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A popular LAN protocol is called Carrier Sense Multiple Access with Collision Detection (CSMA/CD) and, as previously mentioned, is described in IEEE Standard 802.3 and which standards are well known to those skilled in the art and which are incorporated herein by reference. In accordance with the 802.3 protocol, all data communication devices are connected to a common bus and have equal access to the network. A device wishing to transmit must sense bus transmissions and the device itself can transmit only if the bus is idle. However, due to propogation delays between a transmission by one device and the sensing of that transmission by another device, two or more devices may begin transmission nearly simultaneously. A data collision results and a mechanism must be provided to detect the collision and to cause the devices to stop transmission when a collision is detected. A random number algorithm is then used to arbitrate retries.

An illustrative arrangement of a LAN network that is suitable for use with CSMA/CD protocol is shown in Fig. 1. The network consists of backbone 100 and a plurality of local segments of which only segment 102 is shown for clarity. Segment 102 is connected in a well-known manner to backbone 100 by means of repeater units such as unit 104. In a conventional construction, segment 102 may be a coaxial cable.

Attached to segment 102 are transceivers 106 that receive and transmit electronic signals from and to the cable. In a typical prior art construction, transceivers 106 are, in turn, connected to cables 108 which convey the electronic signals to electronic controllers 110 located in data communication devices 112. Such data communication devices may illustratively be computers, printers, file servers or other conventional data devices. In a typical LAN there may be as many as a thousand data communication devices, although typically limited from ten to one hundred devices.

In accordance with the invention, an optical free space network (shown schematically in dotted box 120) may be added to the conventional network. In particular, one or more "suns" (of which sun 130 is shown) are attached to LAN segment 102 via a transceiver 106 and cable 108 as with the conventional construction. The internal construction and operation of sun 130 will be discussed in detail below.

However, the data communication devices 150-156 which are served by sun 130 are not connected directly to sun 130 as with the prior art construction, but are connected via satellites 132-136 and 140 and optical links 142, 144 and 148. The operation and construction of satellites 132-136 and 140 will also be described in detail below.

Each satellite is connected, by means of a cable, to the electronic controller in at least one data communication device. For example, satellite 134 is connected to electronic controller 164 of device 154. Similarly, satellite 140 is connected to controller 168 in device 156. Satellite 132 is connected to two controllers 160,162 in devices 150 and 152, respectively. It is also possible to connect more than two devices to a single satellite. In general, a satellite is either receiving or transmitting optically. It cannot transmit while it is receiving or vice versa.

With multiple suns attached to LAN segment 102, it may be necessary to process signals on segment 102 with a re-timer circuit (not shown). The construction of the re-timer circuit is well-known and its function is to compensate for jitter caused by noise in the optical signals. With this construction, a data bit-stream can be processed virtually in parallel by all communication devices connected to the LAN segment.

Although sun 130 is generally optically linked to satellites through free space, in certain circumstances, sun 130 may connect directly to a satellite 175 by means of a fiber

optic communication line 172. Line 172 conveys light signals to and from sun 130 to data communication device 170 by means of satellite 175 and electronic controller 174. The same light pulses which are broadcast in free space by sun 130 can also be conveyed by fiber optic line 172 to device 170.

As shown in Fig. 1, the sun-satellite optical link replaces the transceiver cables 108 and the transceivers 106 that are required in the prior art construction to connect each data communication devices to LAN segment 102.

It is also possible to use a sun/satellite combination as a repeater. Such a combination is shown in Fig. 1 as satellite 136 and sun 138. Satellite 136 is linked optically, via link 144, with sun 130. Satellite 136 is also linked electronically (by means of a cable or other "hard wire" link 146) to sun 138. To prevent crosstalk, the optical path 144 between sun 130 and satellite 136 must not coincide with optical path 148 between sun 138 and satellite 140. Accordingly, satellite 136 is physically positioned such that it obstructs the line-of-sight optical path between sun 130 and sun 138.

In operation, for transmission in one direction, satellite 136 converts optical signals received from sun 130 to electronic signals and forwards these electronic signals to the receiving electronic system of sun 138. These electronic signals appear to the sun 138 the same as if they were received from LAN segment 102 over a cable 108. Sun 138 converts the electronic signals to optical signals and forwards the optical signals over link 148 to satellite 140 which, in turn communicates with device 156.

In the reverse direction, satellite 140 generates optical signals and transmits them to sun 138 over the optical link 148. Sun 138 converts the received optical signals to electronic signals and places the electronic signals on electronic link 146 just as if the sun 138 was were connected

to, and transmitting to, LAN segment 102. The electronic signals on link 146 are input to satellite 136 and appear to satellite 136 as if they were received from a data communication device. Satellite 136 converts the electronic signals to optical signals and transmits them to sun 130. Satellite 136 is arranged so that it does not receive electronic signals from sun 138 and transmit electronic signals to sun 138 concurrently except to transmit a collision detection signal. In this manner, and because satellite 136 obstructs the optical path between suns 130 and 138, communication between sun 138 and sun 130 is half duplex even though both suns receive and transmit optical signals concurrently. Thus, a circular transmission is avoided. The repeater arrangement formed by the electronically linked satellite 136 and sun 138 allows the range of the system to be extended beyond the maximum optical transmission distance of sun 130.

Another satellite/sun repeater can be linked to sun 130 or to sun 138 to further extend the system. The total number of repeaters that can be linked in a chain is limited by the maximum round-trip signal propagation time between data communication devices situated at the furthest ends of the local area network. Many conventional protocols, for example, IEEE Standard 802.3, specify an upper limit to the maximum round-trip propagation time.

Satellites 132-136 and 140 communicate with sun 130 by means of substantially line-of-sight optical transmission links. Consequently, in the absence of repeater units discussed above, the number of satellites that can be served by one sun is limited by the number of data communication devices that can be installed in an unobstructed area within a predetermined radius related to the maximum reliable optical transmission distance. Typically, the number of data communication devices is between five and thirty.

There are several physical arrangements of the sun and its satellites of which two are illustratively described. In one embodiment, shown as a physical plan view in Fig. 2, sun 200 is mounted on ceiling 202 and transmits and received optical signals in beams 216 and 218 traveling parallel to floor 201 at a predetermined height (H) above floor 201. Height H is preselected to place optical beams 216 and 218 above obstructions, such as people and furniture. Satellites 204 and 206, likewise, transmit and receive optical signals in beams 216 and 218 that are parallel to floor 201 and at the same elevation H as sun 200. Data communication devices 212 and 214, located near the floor 201 are connected to satellites 204 and 206, respectively, by cables which extend over the distance H. With this arrangement, the LAN operator has almost total latitude in situating suns and satellites as long as the length of optical beams 216 and 218 does not exceed the maximum transmission distance and suns and satellites can be relocated easily.

In a second embodiment shown as a physical plan view in Fig. 3, sun/satellite repeater pairs 304/306 and 308/310 are mounted near a single satellite or a small group of satellites (316 and 324, respectively) so that the free-space optical links, 318 and 322, between the repeater suns 306 and 310 and the satellites 316 and 324 are relatively short. For example, repeater 304/306 could illustratively be mounted on a light-weight track 305 attached to a ceiling, wall, or other surface with clips, adhesive, or some other device that does not require special skills or tools to install. Similarly, repeater 308/310 could be mounted on track 312. Repeater 304/306 is positioned along track 305 so that the length of optical link 318 between sun 306 and satellite 316 is short yet an optical path 312 can be established between repeater satellite 304 and central sun 300. A similar optical path 314 can be established between repeater satellite 308 and central

sun 300. The advantage of the embodiment illustrated in Fig. 3 is that it is less prone to interruptions from obstacles which may be in the optical paths. However, this embodiment has less flexibility when the configuration is installed and less flexibility in relocating data communication devices when such relocation is required.

In accordance with the invention, the sun/satellite combinations maintain the integrity of their respective optical links independently of, and transparent to, the LAN. More particularly, in order to insure that each optical link is functioning, each sun, in a well-known manner, periodically generates a special data pulse "heartbeat" signal when it is not transmitting other data information. Each satellite which is optically linked to the sun monitors the sun's transmissions for this periodic heartbeat signal in a conventional fashion. The absence of a heartbeat signal from the sun for a predetermined interval of time is construed as an impairment to the optical link and a signal is generated by a satellite and forwarded to the associated data communication device whenever this kind of event occurs. The data communication device then takes appropriate action such as generating an audible or other alerting signal to cause a person or persons blocking the optical link to move. However, even if one or more optical links become permanently impaired, the overall functionality of a CSMA/CD LAN is not affected because all links are in parallel.

Another LAN function that is independently handled by the sun/satellite combination in a CSMA/CD LAN network is collision detection. In accordance with one aspect of the invention, collision detection can be handled in several ways. For example, one way is to use an optically-sectored sun. In such an arrangement, the sun broadcasts optical information to all associated satellites, but the sun has a plurality of separate "sectors" each of which has an optical receiver that

receives optical information from only one satellite. Consequently, collisions can be detected by noting that one or more sectors are receiving incoming optical information simultaneously.

Should two or more satellites transmit at the same time, the sectored sun handles the collision by transmitting a collision detect signal to all the satellites and simultaneously transmitting a "jam" signal to its associated LAN segment and to all satellites. The form of the jam signal is defined by the requirements of the particular network protocol used on the LAN and are well known to those skilled in the art.

In order to clear the simultaneous transmissions of two or more satellites, the collision signal sent to the satellites is in the form of a clear data pulse followed by the jam signal. The clear data pulse has a pulse length which exceeds the maximum pulse length of any normal signal which would be transmitted by the sun and is thus easily identified by the satellite. Upon receipt of the clear data pulse, any satellite that is in the process of transmitting immediately ceases transmission and goes into an optical receiving mode whereby any optical signal received is passed directly onto the associated data communication device. In this manner, the same jam signal appears at all data communication devices throughout the network as would be the case if the optical links were not in the system. Similarly, in the case that a satellite detects a collision between two data communication devices attached to it, the satellite communicates the collision to its associated sun by transmitting a clear data pulse to the sun. Upon detecting such a pulse, the sun transmits the clear data pulse and jam signal to all of its associated satellites as previously mentioned.

Another method of handling collisions is used in the case of an unsectored sun where all optical signals received at the sun are incident upon one receiving unit. In this latter

case, collision detection is accomplished by passing code signals between the sun and its satellites. In accordance with the invention, the code signals are not passed to the LAN network so that collision detection is independent of the network.

More particularly, Fig. 4 is a block electrical schematic diagram of an illustrative satellite construction. During operation of the satellite, an incoming signal from a data communication device is received at the data communication device interface 400 and passed, via bus 406 to encoder 416. Encoder 416 is a conventional circuit which converts the electronic signals received from the data communication device to a form suitable for optical transmission. In particular, optical transmission in the illustrative embodiment utilizes a data format specified by the LAN protocol requirements. Generally these LAN protocol requirements specify that the data be preceded by a coded protocol defined preamble.

In accordance with one aspect of the invention, the normal protocol defined coded preamble utilized by the LAN is modified to allow communication between the satellite and its corresponding sun only and not the network because of the modified preamble. When the normal protocol defined coded preamble is received by the sun, a predetermined portion of the normal preamble portion is removed and substitute bits added to return it to its normal length and transmitted so that the sun/satellite communication is not received by the network because it is not recognized by the network.

More particularly, in encoder 416, a small predetermined group of bits are removed from the protocol defined preamble and substituted with a special code generated by code generator 412 and provided to encoder 416 by means of bus 414. This special code may take one of several forms, illustratively, a pulse-width-modulation scheme may be used whereby a digital "zero" may be represented by a relatively short pulse

and a digital "one" may be represented by a relatively long pulse. The exact code generated by generator 412 may be set by internal switches or by a pseudorandom number generator located in code generator 412. From encoder 416, the encoded signal is passed to transmitter 434 via bus 436 where the signal is converted to a stream of optical pulses for transmission to the sun. As will hereinafter be described in detail, upon receiving the normal protocol defined coded preamble, the sun immediately re-transmits the modified coded preamble back to the satellite.

The re-transmitted modified preamble is received from the sun by satellite receiver 426 and sent, via bus 430, to decoder 424. Here the special code is separated and removed from the remainder of the received signal. The original protocol defined preamble is regenerated and the preamble and data are passed via bus 408 to the data communication device interface 400 for transmission to the data communication device. The separated code is passed to the comparator 410 for comparison with the original code. If the two codes match, the satellite continues its transmission to the sun, if not, transmitter 434 is disabled by control circuit 420 and the satellite is set to the special receive mode discussed above. Only satellites which are transmitting to the sun perform the aforementioned code comparison. Satellites which are not transmitting simply pass the regenerated preamble and data to the data communication device.

The above operation will detect a collision because should one or more satellites transmit signals simultaneously, the optical signals will be superimposed at the sun. Consequently, the encoded preamble will become modified at the sun and the modified code will be re-transmitted to the satellites. When each satellite makes the above-described comparison of the originally-transmitted code with the received

code, the modified code will be detected by one or more of these satellites causing them to enter a collision mode.

As mentioned previously, it is possible that the signal from one satellite will dominate another, resulting in the smaller signal being "ignored" by the sun. In this case, the collision will be detected only by the weaker satellite, since only this satellite will receive a modified code. Nevertheless, the existence of such a collision can be communicated to the sun and thus to the remainder of the network. In particular, as previously described, a satellite which detects a collision ceases transmission, causing the peak amplitude of the signal received at the sun to drop by an amount equal to the amplitude of its previously-transmitted signal. The sudden drop in signal strength is detected by the sun as evidence of a collision.

More particularly, Fig. 5 shows a block electrical schematic diagram of an illustrative embodiment of a sun. An optical signal from an associated satellite is received by receiver 522 and provided via bus 520 to transmitter 518 for re-transmission to the satellites. The receiver signal is also provided to preamble regenerator 512 which removes the special code inserted by the satellite and forwards the regenerated preamble, via bus 510 to the LAN interface 500.

A drop in signal strength which, as previously mentioned, is indicative of a collision is detected by collision detection circuit 514 (discussed in detail below). When detection circuit 514 detects such a drop in signal strength, it controls jam signal generator 515 to generate a jam signal which forms the LAN network that a collision has occurred. The jam signal output of generator 515 is provided, via bus 508, to LAN interface 500 for transmission to the LAN network. The jam signal is also provided, via bus 516, to transmitter 518 for transmission to the satellite as previously discussed.

Alternatively, if a collision occurs on the LAN network, LAN collision detector 502 controls collision signal generator 506 (via bus 504) to generate a collision signal for transmission to the satellites by means of transmitter 518. The significance of the collision signal is to alert the satellites that a jam signal is about to be sent and communication ceased.

A more detailed block diagram of optical collision detector 514 is shown in Fig. 6. When the encoded signal from the satellite is received by receiver 600, receiver 600 starts timer 606 by means of bus 602. The received signal is also provided, via bus 602, to peak detector 604 where the peak value of the signal is monitored and used to dynamically control divider 610 to generate a threshold level. The threshold level is set typically at a fraction, such as 0.95, times the peak signal value averaged over a predetermined number of previous bit cycles.

The signal generated by receiver 600 is also provided to comparator 614 and compared with the threshold level generated by divider 610. If the received signal amplitude from receiver 600 fails to exceed the threshold level generated by divider 610 during each cycle of the signal, trigger circuit 620 is activated by comparator 614 and a collision signal is generated. Timer 606 disables comparator 614 after a predetermined number of bit cycles of the received preamble because optical collisions are not possible after this time interval.

Waveform diagrams illustrating the operation of the optical collision detector are shown in Figs. 7 A-E. For reference, a clock signal which defines bit times is shown in Fig. 7A. A large amplitude signal is shown in Fig. 7B. The particular signal shown is encoded by means of a pulse width modulation scheme in which a relatively "wide" pulse (with respect to a bit time defined by clock signal shown in Fig. 7A) represents a digital "one" and a relatively "narrow" pulse

represents a digital "zero". The signal shown in Fig. 7B has been arbitrarily encoded with a repeating digital code sequence "0100". A digital signal with a small amplitude is shown in Fig. 7C encoded with the repeating digital code "1001". The superposition of the two signals such as might occur during an optical collision is shown in Fig. 7D. By virtue of the design of conventional optical receivers, the signal in Fig. 7D would be decoded in the same manner as the signal shown in Fig. 7B alone. Consequently, the collision would not be detected and the satellite generating the smaller amplitude signal would effectively be isolated from its associated sun.

The peak amplitude detector shown in Fig. 6 operates to prevent such an occurrence. More particularly, in Fig. 7D, the peak signal level generated by peak detector 604 is shown together with a threshold level derived from the peak amplitude by means of divider 610. As can be seen, during the period when both signals are being received, the peaks of the received digital signal exceed the computed threshold level during each cycle of the clock shown in Fig. 7A. Consequently, trigger circuit 620 is triggered during each clock cycle and no collision signal is generated as shown in Fig. 7E.

However, as previously mentioned, a satellite which detects a collision ceases transmission, causing the peak amplitude of the signal received at the sun to drop by an amount equal to the amplitude of its previously-transmitted signal. Thus, the signal shown in Fig. 7C. will cease when the satellite generating it detects the collision by monitoring code returned by the sun. As shown in Fig. 7D When the signal shown in Fig. 7C disappears, the signal peak level falls below the threshold level and remains there. Consequently, comparator 614 inhibits trigger circuit 620. Trigger circuit 620 is so designed that it must be triggered at least once during each cycle of the clock or a collision signal will be generated as shown in Fig. 7E.

The same mechanism is used by a satellite to indicate a collision between two data communication devices which it services. More specifically, in the event that a satellite detects a collision between two data communication devices, it communicates the collision to its sun by transmitting a long duration pulse to the sun. The length of this pulse is chosen to exceed one cycle of the clock shown in Fig. 7A so that no signal transition through the threshold level will occur during at least one clock interval and the trigger circuit will be inhibited to generate a collision signal as before.

By changing the threshold level generated by divider 610, many variations in signal level may be tolerated without generating a false collision signal.

Networks requiring collision detection that use conventional media for conducting signals such as wire, coax cable, or fiber have electronic means for readily sensing the presence of two or more signals on the medium. In order to provide collision detection with a free space optical link, it is necessary that the powers received by a sun be equal for each satellite. Because the power of light pulses in free space diminishes as the inverse of the square of the distance they have travelled, the presence of simultaneous signals from two or more satellites that are not equidistant from a sun is not easily detected. As a means for maintaining uniform power transmission from a satellite, a fraction of the power emitted by a satellite is directed to an optical detector in the satellite. In this way the transmitted signal is continually monitored and compared to a satellite's reference level. The difference between the output and the reference provides feedback to increase or decrease, as the situation warrants, the drive current to the satellite's light emitter. This feedback circuit overcomes changes caused by aging of the emitter, power supply changes, etc. Electronic/optic apparatus

for performing this function is well known to those skilled in the art.

In addition to the above provisions, a satellite's reference level can require adjustment because of changes in the ambient light cause by the time of day or day of year or because of significant changes in the distance between satellites and sun or because of aging of components and so on. To correct for such variations, the present invention performs the following function. At the beginning of a communication session a sun measures the optical power received from a satellite. A sun encodes the value of power received relative to a reference and inserts the code in the transmission to the satellite; it does not insert the code in the message passed to the local network segment to which it is attached. A satellite that is transmitting reads the code as received from a sun and adjusts its optical transmitter power accordingly. In this way the optical power outputs of all satellites as received by a sun are maintained at an appropriate level and are adjusted whenever necessary to compensate for changes caused by time of day, time of year, relocation of the sun or satellite, aging of components.

The length of the code used to convey information about the amplitude of optical power received is determined by the degree of precision required. Generally, a four-bit code that covers a range of power received of approximately 60% to 140% of the reference value will provide sufficient resolution to facilitate accurate detection by the sun of the simultaneous presence of two or more optical signals.

The code used to convey information about the amplitude of optical power is superimposed in the first portion of the normal protocol defined preamble as disclosed above for the modified preamble used between satellite and sun.

Electronic/optic apparatus for performing the power monitoring and power adjustment functions are well known to those skilled in the art.

Considering now another popular LAN protocol commonly referred to as a "token passing ring" the data communication devices are physically and sequentially connected together in a ring network. A special data word (which includes a priority indication) called a "token" is transmitted from station to station and circulates around the ring. A data communication device desiring to transmit does so when it receives the token and the token priority indication indicates a priority which is less than or equal to the priority of its transmission.

The resulting data stream which circulates around the ring is formatted as tokens and "frames". A typical format for a token is three sequential data words, each of which has a specified bit pattern. The second and third words of a token can be modified by data communication devices. The format for a frame includes the first two data words that are used with a token plus additional words which are used by address and message information and a final word for frame status. Some of the frame words can also be modified by data communication devices. These bit-streams are processed on the fly by the data communication devices. Due to the propagation times of the signals in the network, all active data communication devices will be processing segments of the token simultaneously.

In accordance with the invention, the disclosed optical link system can be used to link data communication devices in series to form a ring network. The optical paths can be line-of-sight or reflected.

Fig. 8 shows an illustrative embodiment of a token passing ring LAN. Assume, for example, that data originates at data communication device 814. The data is passed from device 814 to its associated satellite 808 as electronic signals.

Transmitter 812 of satellite 808 converts the electronic signals to optical signals and transmits them to receiver 806 of sun 802. Receiver 806 converts the optical signals to electronic signals and transmits them to LAN segment 801. Transmitter 818 of sun 816 receives the electronic signals converts the electronic signals to optical signals and transmits the optical signals to receiver 824 of satellite 822. Receiver 824 then forwards the electronic signals to data communication device 828.

In a similar manner, device 828 forwards information to data communication device 842 via the path consisting of transmitter 826 of satellite 822, receiver 820 of sun 816, LAN segment 801, transmitter 832 of sun 830, receiver 838 of satellite 836. This process is repeated for all workstations linked with LAN segment 201.

The output of the last device on the LAN segment 801 is transmitted to the ring. For example, if device 842 is the last device on the ring, device 842 forwards information to satellite 836, which, in turn, sends the information to the ring via satellite transmitter 840 and sun receiver 834.

In accordance with conventional token ring LAN operation, the data signals propagate around the ring and are presented to the input side of segment 801 where they are provided to transmitter 804 of sun 802. Transmitter 804 converts the electronic signals to receiver 806 of satellite 802 and thence to data communication device 814. In this manner, a bit-stream is processed sequentially by all devices on the ring network and then returned to the originating device.

The operation of optical token ring networks such as that shown in Fig. 8 is subject to problems of crosstalk and reliability. Fig. 9 illustrates a physical sun/satellite configuration in which such crosstalk could occur. Satellite 900 is optically linked with sun 902, satellite 908 is linked

with sun 904 and satellite 910 with sun 906. In normal operation light 912 generated by satellite 900 is received by sun 902. Similarly, light 914 generated by sun 902 is received only by satellite 900. Sun 904 and satellite 908 communicate via light beams 916 and 918 and sun 906 and satellite 910 communicate via light beams 920 and 922. However, since suns 904 and 906 and satellites 908 and 910 are physically close together, light 916 from sun 904, which is intended for satellite 908, could spread as a stray light beam 926 and be detected by satellite 910 because it is close to satellite 908. Likewise, stray light beam 924 from satellite 908 could be detected by sun 906. Also, satellite 908 could communicate with satellites 900 or 910 and vice versa. Any of these events would disrupt the sequential processing of bit-streams.

The aforementioned crosstalk problem can be dealt with in several ways. First, the optical transmitting wavelength of each sun/satellite pair can be restricted to a unique range. This result can be achieved by optical bandpass filters or by using light emitters and detectors that operate at significantly different optical wavelengths. Second, for example, Figs. 10 and 11 depict a multi-channel network in which each satellite receives and transmits on a predetermined channel carrier frequency or a set of channels of relatively narrow bandwidth while the sun transmits and receives a multiplexed set of channels occupying a bandwidth sufficient to include all of the satellite channels carrier frequencies simultaneously.

Fig. 10 shows an illustrative set of channels as they might be assigned within the sun in which the horizontal axis denotes carrier frequency while the vertical axis represents signal power in arbitrary units. Each channel is assigned a bandwidth of C and the entire system bandwidth is W. As shown in Fig. 10, the channels are centered at frequencies Fi, Fj, Fk, Fl, Fn, Fm, etc. Illustratively, channel Fi might be a

channel with a 10 MHz bandwidth centered about a frequency i of 50 MHz whereas channel Fj might be a channel with a 10 MHz bandwidth centered about a frequency i of 60 MHz. The remaining channels are assigned in a similar manner. The channels are referred to by their center frequencies in the discussion below, that is, the channel centered at frequency Fi is referred to as channel Fi.

During operation of the network, the sun broadcasts a modulated optical beam in which the transmitted information is impressed on upon the optical beam by analog, digital or combinational methods well known in the art. The optical frequency of the beam is not intentionally modulated, i.e. the illustrative system is not an optical wavelength division multiplexing scheme. Although many different schemes may be used to assign transmission frequencies to each sun/satellite pair, it is preferable that the communication between a sun and a satellite take place in adjacent channels. For example, a sun may transmit to a first satellite at frequency Fi and receive information from that satellite at frequency Fj. Similarly, the sun may transmit to a second satellite at frequency Fk and receive information from that satellite at frequency Fl.

In order to operate as a token ring network, the simultaneous transmissions between suns and satellites in a multi-channel system must be broken into serial transmissions. Referring to Fig. 11, a mechanism for serializing the simultaneous bi-directional flow of signals between suns and satellites is illustrated. In Fig. 11 optical power is transmitted through free-space medium 1102, between sun 1100, and an illustrative satellite 1104. As previously mentioned, the optical signal broadcast by sun 1100 is a composite of channels Fi + Fk + ... + Fn. Similarly, sun 1100 receives the sum of all signals, Fj + Fl + ... + Fm, transmitted by

satellites within view. This bi-directional signal flow is represented by arrows 1127 and 1131 in region 1102.

An illustrative sun 1100 is shown in block schematic form. In general, a data signal Fo in the form of a bit-stream may be introduced to the sun from the remainder of the LAN network at bus port 1114. The data signal, Fo, passes to modulator 1106 where it modulates a carrier signal at frequency Fi to form channel signal Fi. Channel signal Fi is provided to multiplexor 1122 where it is multiplexed with other channel signals. The resulting composite signal is passed to optical transmitter 1126, which as will hereinafter be described, comprises driving electronics and an optical power source such as a laser or light-emitting diode.

Assume, for the purpose of illustration, that, at the point in time when signal Fo first modulates carrier signal Fi, the other channels carry no data signals. In this case, the optical signal in channel Fi passes to satellite 1104 which is shown in block schematic form. Although user interface 1142 is shown in Fig. 11, it is not part of satellite 1104 but is an element which is generally located within the data communication device. Satellite 1104 receives the optical signal from sun transmitter 1126 in optical detecting element 1130, which might illustratively be a photodiode. The received signal is provided to a bandpass filter 1134 to separate channel signal Fi from the composite signal generated by sun 1100. The channel signal Fi is then demodulated by demodulator 1138 to recover the original signal Fo which is then passed to the user interface 1142.

The user interface interacts with the data communication device (not shown) and after a time delay of a few bits, returns the bit stream Fo (with or without modifications) to satellite 1104 via bus 1141. For convenience, the same notation (Fo) is used for the modified and unmodified bit stream. The actual contents of the bit stream Fo are not

important to the operation of the optical network. The data signal Fo is provided to modulator 1140 where it modulates a carrier signal of frequency Fj to create a channel signal Fj. From modulator 1140 the channel signal is provided to an optional bandpass filter 1136 of bandwidth C centered at frequency Fj. The channel signal Fj is then transmitted by means of optical transmitter 1132 back to sun 1100 where it is received, along with other channel signals, by detecting element 1128. The composite signal is demultiplexed by demultiplexor 1124 where channel Fj is separated from other satellite channels. Channel signal Fj then passes to driver circuit 1108 which, in turn, drives frequency shifter 1110. Shifter 1110 converts the carrier signal frequency Fj of channel Fj to a new carrier frequency Fk. The resulting channel Fk signal is forwarded to multiplexor 1122 where it is multiplexed with channel Fi (from modulator 1106) and re-transmitted (as previously discussed) to all satellites simultaneously.

The channel Fk signal is received by a satellite assigned to channel Fk (not shown) which processes channel Fk in a manner similar to that described above and passes the data signal Fo back to sun 1100 via another channel signal Fl. This process continues and, within a short period of time following start-up, all channels are occupied with portions of the data bit-stream Fo which passes through the various channels in a serial fashion.

Eventually, the Fo data signal passes to frequency shifter 1116 where it is converted to channel frequency Fn and transmitted to the last satellite in the ring. The returning bit-stream in channel Fn is provided to a demodulator 1120 which recovers the data stream Fo which has been modified by all data communication devices in the optical network. From demodulator 1120, the data stream Fo is passed to the remainder

of the LAN network by means of interface 1114 or, alternatively, the Fo signal may be passed back to the modulator 1106 for re-transmission through the optical ring.

Although the transmission fo the Fo signal through the optical ring has been illustrated assuming that communication between a sun and its satellite uses different carrier frequencies, it is also possible that the communication between a sun and satellite can use a single carrier frequency. For example, in the previous discussion carrier frequencies Fi and Fj could be the same frequency, frequencies Fk and Fl could be the same frequency (but different from frequency Fi) and frequencies Fn and Fm could be the same frequency but different from any other frequency shifter 1110, ..., 1116. Consequently, in the event that signal degradation occurs or that access to the bit stream Fo is required, the bit-stream Fo is available at the sun essentially between channels.

In another embodiment, channel frequencies Fi and Fj may be different, but frequencies Fj and Fk may be the same. Similarly, frequencies Fk and Fl may be different (frequency Fl is different from frequency Fi) and so on. With this frequency arrangement the sun transmits to and receives from a satellite in different channels and each satellite receives and transmits in different channels. However, adjacent channels transmit and receive in the same channel so that the frequency shift which is necessary between channels is effectively carried out in each satellite. This arrangement has the advantage of simplifying the circuitry of the sun without adding to the complexity of the satellite. More specifically, frequency shifter elements 1108 and 1110 in the sun receive channel frequency Fj but it is not necessary to shift this frequency to another frequency since the channel information will be re-transmitted at the same frequency Fk (frequency Fk equals frequency Fj). Therefore, the frequency shifter elements 1108 and 1110 may be replaced by an amplifier, impedance matching network, or a

single wire, depending upon details of the selected circuits in the multiplexor 1126 and demultiplexor 1128.

It is also possible to establish serial connections between a sun and its corresponding satellites by physically separating optical signals passing between suns and satellites and by using different frequency channels to communicate between suns and satellites instead of using a different frequency for each satellite as previously described. For example, it is possible to have the optical receivers in a sun highly collimated such that only light directly aimed at such a sun by a satellite will be detected. With such a system, in order the avoid crosstalk, the optical transmission frequency used by the sun to transmit to all of its satellites would be at a different frequency than the optical transmission frequency used to transmit from the satellites to the sun. Further, in order to avoid crosstalk between adjacent satellites, each satellite would be signed to optically detect only the frequency which the sun transmits.

An illustrative example of a sun using collimated receives is shown in Fig. 12 which depicts sun 1200 physically segmented into four 90° sectors 1220-1226. Illustratively, the receiver 1206 for segment 1226 is connected to a segment 1202 of a LAN token ring (not shown). Receiver 1206 receives electronic signals on segment 1202 and converts them to optical signals as mentioned previously. The optical signals are broadcast in a beam 205 that propagates in a direction normal to the sun and fills 90° sector 1207. A satellite such as satellite 1210 located in the path of beam 1205 receives the optical signals in receiver 1208 and converts the optical signals to electronic signals which are, in turn, transmitted to data communication device 1211.

Similarly, electronic signals from data communication device 1211 are converted to optical signals and transmitted back to the sun via satellite transmitter 1218. Signals from

satellite 1210 are received by sun receiver 1228 whose output drives optical transmitter 1230 of sector 1224. Sector 1224 generates an optical beam which fills 90^{o} sector 1232 in which satellite 1212 is located. Satellite 1212 communicates with sun 1200 in a manner similar to satellite 1210 to link its associated data communication device 1213 to the network. Signals received from satellite 1212 in sun sector 1224 are passed on to sector 1222 which communicates with satellite 1214 and device 1215. Similarly, signals received from satellite 1214 are passed on to sun sector 1220 and satellite 1216 and device 1217. Optical signals received by sector 1220 from satellite 1216 are converted to electronic signals and impressed on LAN segment 1202 to complete the ring.

In addition to the four-sectored sun shown in Fig. 12, the sun optical configuration can be broken into many more sectors. The more sun sectors there are, the more flexibility there is in positioning satellites. However, as the number of sectors increases, the difficultly of maintaining physical optical separation likewise increases.

An inherent vulnerability of the above-described optical ring networks is that if a single link becomes impaired, the entire network will cease functioning. While this vulnerability exists with metallic conductor or cable networks, the technology to deal with link failures in such "hard-wired" networks is more mature and therefore recovery processes may be easier to implement than similar processes in optical links.

However, reliability of the optical link network can be improved by providing secondary or backup links or by removing impaired links. In accordance with the invention, by means of transmissions between the sun and its satellites these impaired links can be switched out automatically without involving the remainder of the network.

In particular, a nonfunctioning satellite can be "short-circuited" from the ring by connecting the satellite preceding the nonfunctioning satellite with the satellite following it. This is accomplished by comparing the information in a transmission to a satellite with the same information transmitted back from the satellite. The comparison is actually performed by passing the information transmitted to a satellite through a short delay line and comparing the delayed information with the returning information from the satellite. If no message is received from a satellite within the maximum delay time and round trip propagation time, it can be assumed that the satellite is either nonfunctional or the optical path has become impaired.

In the case of an impaired link, if transmission to the impaired satellite has not begun, the sun simply transmits the delayed information to the next satellite in the ring. If the path becomes impaired after the sun short circuits the satellite and, if desired, can transmit an error or abort signal to the LAN ring.

Fig. 13 shows an illustrative system to delay a bit-stream and to short circuit a free-space link if it becomes impaired. Ring LAN bus 1300 is on the upstream side of sun 1031. The incoming bit stream on bus 1300 is provided, via bus 1310 to packet timer 1304, clock 1306 and delay circuit 1308. In a conventional fashion, clock 1306 monitors the bit information and develops clocking signals. The clocking signals are provided, via bus 1330, to first in-first out (FIFO) register 1308. Register 1308 may illustratively be a shift register which, in response to the clocking signals, shifts the incoming information into the register stages. Thus, the incoming information is loaded into FIFO register 1308.

Incoming signals on line bus 1310 are also conveyed to optical transmitter 1312 which converts the signals to optical signals and transmits the signals to an associated

satellite and data communication device (not shown). After processing by the data communication device as previously discussed, the information is returned to optical receiver 1314 in sun 1301. Receiver 1314 converts the optical signals to electronic signals which are conveyed on bus 1316 to out clock 1320 and delay line 1318.

Clock 1320 is constructed such that it operates like an electronic flywheel, that is, once started, it continues to provide clock control signals for a predetermined time interval after the signals on bus 1316 cease. The clock control signals generated by clock 1320 are provided to delay 1318 and, via bus 1332 to FIFO register 1308. Consequently, under control of the clock signals, the information stored in register 1308 is read out and incoming information from receiver 1314 is read into delay 1318. Delay 1318 is a short delay register which serves to compensate for any delays in retrieving the information stored in FIFO register 1308. The output from FIFO register 130 on line 1326 and output from delay 1318 on line 1334 are provided to gate 1322 and the output of OR gate 1322 is provided to bus 1324 which is the downstream side of the LAN ring network.

In order to switch between links, the incoming bit stream on bus 1310 is also provided to packet timer 1304. The bit information activates packet timer 1304 to begin a timing interval at the beginning of a data packet. Packet timer 1304 is adjusted to generate a time interval equal to the maximum information processing time at the satellite and associate data communication device plus the maximum round trip propagation time of optical signals between sun 1301 and its associated satellite (not shown). This time interval is the number of bit time differences between signals on bus 1310 and bus 1316 and may be used to dynamically calculate the effective length of FIFO register 1308 in a well known manner.

If an incoming signal on line 1316 is received from receiver 1314 within the time interval generated by timer 1304, the optical link is assumed to be operational. In this case, timer 1304 controls out clock 1320 to clock the delayed signal in delay line 1318 to OR gate 1322 and thence to the LAN network 1324. Thus, the information received from the associate satellite is forwarded to the LAN network.

On the other hand, if a signal on line 1316 is not received during the time interval generated by packet timer 1304, the packet timer 1304 controls clock 1306 to clock the incoming information stored in FIFO register 1308 to OR gate 1322 and LAN network 1324. Consequently, if the optical link is impaired, incoming information is shunted through the sun directly to the down stream side of the LAN segment, thereby effectively "short-circuiting" the impaired link.

Packet timer 1304 remains activated until a reset signal from reset circuit 1302 is received. Reset occurs when it is determined that the optical link is viable. Thus, once a link impairment has occurred, the link remains removed until the optical link is determined to be viable.

It is also possible to use the physical sun/satellite configurations shown in Figs. 2 and 3 and discussed with respect to CSMA/CD networks, for token ring networks such as those shown in Fig. 14. Fig. 14 shows a switchable network which can be readily switched back and forth between a configuration suitable for a CSMA/CD network and a second configuration suitable for a token passing ring network. More specifically, the network consists of sun 1400-1404 which communicate with satellites 1406-1410, respectively. Satellites 1406-1410, in turn, communicate with data communication devices 1412-1416. Suns 1400-1404 are connected to the LAN segment consisting of buses 1450 and 1452. In the positions shown in Fig. 14, switches 1430, 1432 and 1434 connect sun receivers 1420, 1424 and 1428 in parallel to LAN segment bus 1450 to provide a

configuration in the topology of a CSMA/CD LAN network. Alternatively, when switches 1430, 1432 and 1434 are switched to their dotted position, sun transmitters 1418, 1422 and 1426 are connected to LAN segment bus 1452 and the suns are connected in series. This configuration is the topology of a token passing ring network.

Figs. 15A-15C show an illustrative optical transmitter/receiver element which may be used with a sun element as described above. As shown in Fig. 15A, the transmitter/receiver consists of light sources 1508-1512, a light detector 1502 and a pair of conical reflecting surfaces 1504 and 1506. More particularly, in the transmitter portion of the circuit, electrical conductors 1508-1512 convey electronic signals to one or more light sources 1514-1518 where the electronic signals are transformed to light pulses. Illustratively, light sources 1514-1518 can be laser diodes or light-emitting diodes. Light pulses emitted from sources 1514-1518 are conveyed by fiber optic elements 1520-1524 to optical diffusion element 1500. Since several light sources are connected to a single diffuser, the optical system has some degree of redundancy in the event that a single light source fails. In addition, the light power output of a sun is increased by using multiple sources.

The output light from diffuser 1500 is projected onto parabolic reflector 1504. Reflector 1504 has a reflective surface which is conically-shaped and is formed by rotating a parabola section around an axis perpendicular to the parabola axis. The surface used is shown constructed as shown in Fig. 15C. In particular, the reflector surface is a portion of a parabola 1571 which has its axis on the X-axis. As shown in Fig. 15C, the focal point of the parabola lies at the X,Y point (2,0) and the parabola intersects the X-axis at the X,Y point (1,0). The reflector conical axis 1570 is perpendicular to the parabola axis (X-axis). The reflector surface is formed by

revolving the parabola portion 1572 extending from the X,Y point (2,2) outward around axis 1570 as indicated by arrow 1574. By varying the parameters of the parabola, a conical surface with a varying conical angle can be generated.

The diffusion element 1500 is located at the focal point of the parabolic section (at point (2,0) shown in Fig. 15C) so that the parabolic shape focuses the reflected light into a disc of predetermined thickness in a direction that is normal to the axis of conical reflector 1504. Optional cylindrical lens 1530 focuses the light even further. Satellites which receive the light transmitted by the optical elements are located in a ring around the axis of cone 1504. Reflectors (not shown) can be used in a conventional manner to reduce the azimuth of the disc of light from 360° to some lesser value such as 180° or 90°. A sun installed in a corner, for example, need have a working sector of only 90°. It is also possible to transmit and receive optical signals to and from fiber optic communication lines as well as free space. For example a fiber optic cable can be aligned with lens 1530 for transmission and another fiber can be aligned with lens 1532 for reception.

Advantageously, in accordance with an aspect of the invention, the disk of light generated by the illustrative optical device is sufficiently bright to transmit to satellites at a reasonable distance, but sufficiently uniform and diffuse so that it will not damage the eye of a person looking directly at the source.

In the receiver portion of the optical element, incoming light pulses from a satellite pass through cylindrical lens 1532 and are reflected from the surface of conical reflector 1506 onto optical diffusion element 1502 (which is located at the focal point of the reflective surface in a manner similar to the transmission side of the sun unit). Light passes through the diffuser 1502 to one or more fiber optic

elements 1550-1552 and thence to light detectors 1560-1562. As with the transmitter, more than one fiber optic element can be optically connected to the diffuser 1502. Light detectors 1560-1562 (which may illustratively be photodiodes) transform the incoming light pulses into electronic signals which are conveyed, via conductors 1564-1566, to the remainder of the sun circuitry. It can be seen that light sources 1514-1518 and light detectors 1560-1562 may be located some distance from diffusion elements 1500 and 1502, respectively because connections are by fiber optic elements.

Incoming light pulses may also be reflected from parabolic surface 1506 directly onto light detectors 1560-1562 without intervening optical elements. In a similar manner, light sources 1514-1518 may direct outgoing light pulses to the reflecting parabolic surface 1504 without intervening optical elements.

Fig. 15B show a perspective view of an illustrative sun element which uses the optical system of Fig. 15. Elements which correspond in Figs. 15A and 15B have been given corresponding numerals. Reflectors 1504 and 1536 may illustratively be made of vacuum-formed plastic which has been metallized with a thin layer of gold or other reflecting metal. In the embodiment shown, upper reflector 1504 and lower reflector 1536 need not have the same conical angle. In particular, angle 1580 may illustratively be 120° and angle 1582 may be 90°. Upper reflector 1504 reflects optical signals generated by emitter/diffuser unit 1500 which may illustratively be a laser diode. Emitter/diffuser 1500 is driven, via cable 1584, from electronics 1586 well known to those skilled in the art. Lower reflector 1536 reflects incoming optical signals generated by other satellites (not shown) and focuses the incoming optical signals onto detector 1502. Detector 1502 is, in turn, connected to electronics 1586 via cable 1588. The entire unit is mounted in a clear housing 1590 which protects

the elements from contamination. An opaque band 1592 around the lower part of housing 1590 shields detector 1502 from extraneous light and optical noise. The illustrated sun unit may be mounted on a ceiling or on a wall by means of a bracket 1594.

Figs. 16 and 17 show an alternative optical system for a sun that is advantageous for use in systems which require separate optical channels between the sun and each satellite. The optical elements are equivalent for receiving and transmitting, consequently, for clarity only a receiver is shown in Figs. 16 and 17. Reflector 1600 is a right angle pyramid in which the angle at the vertex is 90° and the surfaces elements are flat. As shown in Fig. 17 the pyramid is a tetrahedral pyramid, but other solid shapes may be used if more than four channels are needed (in Fig. 17 parts which correspond to similar parts in Fig. 16 are designated with corresponding numerals). The axis of pyramid 1600 is vertical. An incoming horizontal light ray 1602 from a satellite is reflected from the surface 1612 of pyramid 1600 to cylindrical lens 1604 where the light beam is focused onto the end of fiber optic bundle 1606 and thence conveyed to photodetector 1608. Additional fibers and detectors (not shown) can be placed around reflector 1600; one fiber/detector pair corresponding to each face of the pyramid in order to provide the required number of separate optical channels.

Fig. 18 shows still another alternative optical system which can illustratively be used in a sun. The optical arrangement is similar to that shown in Figs. 15A-15C and corresponding elements have been given corresponding numerals. For example, diffuser 1800 corresponds to diffuser 1500. A comparison of Figs. 15A-15C and 18 indicates that fiber optic elements 1870,1872 have replaced the function performed by a conical reflector 1504 in Fig 15A. Fiber optic elements 1870

and 1872 convey optical signals to be transmitted to cylindrical lens 1830. Cylindrical lens 1832 gathers light transmitted from a satellite and focuses the light onto the end of fiber optic elements 1880 and 1882 in order to covey the light to the receiving diffuser 1802 and associated detectors. In the Fig. 18 embodiment, two fiber optic elements are required for each satellite/sun optical path, one optic element for transmission and one optic element for reception. It is also possible that the fiber optic elements 1870,1872 need not be directed to a single detector or transmitter. In some circumstances it is advantageous for a sun to have separate optical channels and, in this case, each receiver fiber optic element can be connected to a separate light detector and each transmitter fiber optic element can be connected to a separate light emitter. The number and physical placement of fiber elements and lenses used in the latter configuration is such that the separate optical paths to and from a sun do not overlap.

Fig. 19 shows an illustrative optical system for use in a satellite. The optical system consists of two plane/parabolic reflectors 1900 and 1902 and receiver 1904 and transmitter 1906. Reflectors 1900 and 1902 are positioned in the disc containing light beams transmitted by a sun such as that shown in Figs. 15A-15C so that light enters horizontally as illustrated by light beam 1908. As shown in the perspective view of reflector 2000 of Fig. 20A, reflectors 1900 and 1902 have a parabolic contour in two dimensions and are either flat or semi-circular in the third dimension. The parabolic contours are arranged so that the focal point of the parabola is not in the line of view but the source or detector can be located at the focal point. Thus, light from a light source 1906 is reflected from surface 1900 and the reflected light is not obscured by the source 1906. Similarly, light reflected from surface 1902 and focused to fall on photodetector 1904, which is not in the path of the incoming light. Both source

1906 and detector 1904 are connected to, and convey signals to, electronic system 1920.

Fig. 19A is a perspective view of the reflector element shown in Fig. 19. Elements which correspond in Figs. 19 and 19A have been given corresponding numerals. As with the reflectors illustrated in the sun unit shown in Fig. 15A, the reflector unit 1901 may illustratively be made of vacuum-formed plastic. The reflective surfaces 1900 and 1902 may then be metallized with a thin layer of gold or other reflecting metal. Illustratively, emitting angle 1932 may be 55°.

As shown in Fig. 20A, light reflected from the surface 2002 of the reflector 2000 is received by photodetector 2004 in a cone of angle ϕ. Surface 2002 gathers light from a height B in the vertical plane and focuses it on detector 2004. Surface 2002 may be either flat in the horizontal plane as shown in the top view in Fig. 20B or semi-circular as shown in the top view in Fig. 20C. Because surface 2002 is flat or semi-circular in the horizontal plane and the detector is located at the focal point of the parabola (and the center of the semi-circular reflector), the amount of light focused on detector 2004 is equal to the amount of light falling on an area equal to the height (B) times the width (A) of reflector 2002. Therefore, the width of surface 2002 can be chosen such that light deviating from normal incidence by an angle ϕ will still be focused on detector 2004. Thus, detector 2004 can be rotated by an angle of $\pm \phi$ with respect to a sun and still receive optical signals. Height B is selected to provide enough light energy to detector 2004 so that it will operate properly.

Fig. 20E is a perspective view of the reflector 2000 shown in Fig. 20A arranged to provide an optical system to accommodate multiple protocols, for example voice and data, voice, data and telephone, etc.. As in Fig. 20A, wherein detector 2004 is located at the focal point and out of line of

view to prevent obscuring received light, detectors 2006-2012 lie coincident with a focal line 2014 to receive light reflected from the surface 2002. It can be seen that the length of the focal line 2014 must be less than the width A of the reflector 2000 so that each of the detectors 2006-2012 can be rotated an angle $\pm \phi$ as explained above with respect to a sun and still receive optical signals. To accommodate multiple protocols on one channel, each of the optical signals associated with a different protocol in a channel in the optical system are of a different wavelength. A respective detector 2006-2012 includes a color filter 2014-2020 corresponding respectively to the wavelength of the optical signal carrying a given protocol so that only the detector associated with a given channel can receive the corresponding wavelength optical signal and reject all other wavelengths optical signals. Likewise, light sources would include corresponding color filters so that optical signals are transmitted at the given wavelength. Therefore, a sun constructed in accordance with Fig. 20E provides a multi-channel optical system capability to accommodate multiple protocols.

Fig. 21 shows another embodiment of optical elements for use in satellite. As with the optical system shown in Fig. 20, the optical system of Fig. 21 is positioned in the disc containing light beams transmitted by a sun. The optical elements are housed and held in position by a fixture 2100 which is supported by a rod 2102. A lens 2104 is used to gather light from a sun and focus the light onto the ends of one or more light conducting fibers 2106. Fibers 2106 convey light pulses to an optic/electronic transducer (not shown) in the satellite. Lens 2108 is used to focus light generated by the satellite and direct it to a sun. The focused light is gathered from the ends of optical fibers 2110 which convey light pulses from a light source in the satellite.

Still another embodiment of a satellite optical system is shown in Fig. 22. As with the embodiment shown in Figs. 15A-15C and 21, plane reflector 2202 is positioned in the disc containing light beams transmitted by a sun. Reflector 2202 is set at an angle of 45° with respect to these beams and enclosed in a housing 2200. Incoming light beams reflected from reflector 2202 are conveyed to lens 2204 which performs the same function as lens 2104 in Fig. 21. Likewise, light beams emitted from fiber optic element 2210 are focused by lens 2208 and reflected by reflector 2202 towards a sun (not shown).

Fig. 23 shows another configuration of optical elements that can be used as the optical system in either a sun or a satellite. The configuration illustrated in Fig. 23 is particularly useful in a network system in which a sun serves individual satellites or a small number of satellites such as the system shown in Fig. 3. As shown in Fig. 23 axis 2300 is the axis for all of the optical elements, including spherical reflector 2302, lens 2304 and planar reflector 2306. The co-linear placement of the optical elements greatly facilitates the process of aligning the sun or satellite. For transmission, lens 2304 focuses light emitted from a light source 2308 and projects the light toward a sun or satellite.

For reception, incoming light is reflected from surface 2312 of spherical reflector 2302 to planar reflector 2306. Photodetector 2310 is positioned to receive incoming light reflected from planar reflector 2306.

For alignment purposes, visible light source 2314 is positioned such that light emitted from it is reflected by surface 2312 of spherical reflector 2302 and projected along axis 2300; however, planar reflector 2306 prevents the light generated by source 2314 from reaching detector 2310. The visible light is transmitted to the receiving site and appears as a visible ring surrounding the reception area. With this arrangement, light is transmitted in a relatively wide cone and

light can be received from a relatively wide cone, thus reducing the precision required in aligning an optical link between a sun and a satellite.

Figure 24 shows an illustrative light source which can be used in the optical design disclosed above. This source overcomes a disadvantage of semiconductor laser light sources which, due to high intensity and small, irregular emitting area, may possibly damage the eyes of a person who looks directly at the source. The potential health hazard of lasers is due to brightness per unit area of emitting surface (which can be considered as a point source) and to the laser's coherent output. For instance, even though a light-emitting diode (LED) emits the same amount of light as a potentially hazardous laser diode, the LED is generally considered safe because it is not a point source and the emitted light is not coherent. Consequently, LEDs are used in many products available to the public, such as TV tuners and toys, without requiring a safety warning regarding hazardous radiation.

The illustrative source consists of semi-conductor laser 2400 and elliptical reflector 22402. Reflector 2402 is a partial ellipsoid and the light-emitting laser diode 2400 is located at one focal point and optical fiber 2404 is located at the other focal point. The reflector shape and the laser diode and fiber placement cause light emitted from the laser diode 2400 to be focused onto the end of fiber 2404. The diameter of fiber 2404 is selected to increase the apparent emitting area of the laser diode to a size which permits safe viewing by nearby personnel. For example, a typical laser emitting area is 1 microinch by 2 microinches. Consequently, if a fiber with a diameter of one millimeter is used, the effective light emitting area will be increased by a factor of one million. The increase in emitting area insures that the light source will pose no threat to the eyes of a person who stares at the light source for a length of time measured in hours.

In addition, the length of fiber 2404 is selected so that the internal reflection which occur as the light travels down the fiber cause the light energy to be more or less evenly distributed in a radial direction even though the source itself may have an emitting area which has high and low intensity area. Illustratively, a fiber with a length of at least 2 1/2 centimeters can be used with a laser operating at an infrared wavelength of approximately 800 nanometers to achieve substantially uniform radial distribution.

An alternative configuration which increases emitting area and creates uniform radial distribution is shown in Fig. 25. In this arrangement, a laser 2500 is mounted in the center of a spherical reflector 2502 and a fiber 2504 is mounted in the center of an opposing spherical reflector 2506. If the focal length of reflector 2502 is equal to the focal length of reflector 2506 and the optical distance between the two reflectors is equal to the focal length, light emitted from laser 2500 will be focused onto the end of fiber 2504. As with the previous embodiment, the diameter and length of fiber 2504 can be chosen to increase effective emitting area and achieve radial uniformity.

Fig. 25A illustrates still another method for rendering a laser diode safe, in effect making its output nearly equivalent to that of an LED. As shown in Figure 25A, laser diode 2510 emits light rays 2520 onto the face of an optical diffuser element 2530. The diffuser corrects for the effects of unequal radial distribution of light rays from the laser mentioned above. If the diffuser has a graded index of refraction (the index of refraction varies as a function of the distance from the axis of the diffuser), it can also be used to collimate the light. Diffuser 2530 is, in turn, optically linked to a multiplicity, n, of optical fibers 2540. The laser output 2520 which appears as a single point source is thus converted to an apparent array of n point sources. Light rays

2550 emerge from the output ends of fibers at an angle determined by the numerical aperture of the fibers.

The area of the input face 2560 of diffuser 2530 increases the apparatus emitting area of diode 2510 and the multiplicity of fibers 2540 increases the number of light sources, the combination of these two features makes the laser appear like a LED and, consequently, as safe as a LED.

As disclosed above, optical means to increase output light power and to provide redundancy consisted of coupling each light source to a fiber optic element and combining all such fiber optic elements into a single fiber optic element and the single fiber optic element being positioned at the focal point of a focusing reflective cone. The light distribution pattern of a laser diode results in a highly efficient coupling between the diode and a fiber optic element. The light distribution pattern of a non-laser light emitting diode is such that the coupling between a LED and a fiber optic element is very inefficient. Another method for increasing the output light power of non-laser LED's without incurring the losses associated with the combination of a LED with a fiber optic element is to utilize the maximum amount of light energy radiated from a light emitting diode.

Considering Fig. 26, a cross section view of a typical light emitting diode LED well known to those skilled in the art and generally designated 2600 is illustrated wherein the LED includes input electrical connectors 2602, 2604, a base plate 2606, a die 2612 that converts electrical current to infrared light, a wall 2608 surrounding the die, a lens 2614, a window 2610 through which light emitted by the die passes and electrical connections 2616 and 2618 connecting the die to the connectors 2602 and 2604, respectively. It can be seen that light rays less than angle 2620 are able to pass through the window 2610 and rays greater than angle 2620 impinge on the surface of wall 2608. Angle 2620 is the Arctan of half the

interior diameter of wall 2608 divided by the height of wall. Generally, these rays do not reflect off the wall 2608 and pass through the window 2610. A typical radiation pattern from a LED is a nearly uniform distribution ± 90° so almost half of the light impinges the interior surface and, hence, does not exit the device package.

Commercially available high-powered light emitting diodes radiate 40 milliwatts of infra-red light. Unobstructed by the package, the total light emitted is 60+ milliwatts. One method to increase the light output power is to make available at least some of the light that cannot exit the package through utilization of a light emitting diode without a package.

Fig. 27 is a graphical representation showing the percentage relative radiation intensity as a function of ray angle from the axis of the LED. Generally, the intensity is fairly uniform. The amount of energy radiated as a function of angle θ is expressed as $P\theta = Ptotal\ (1-\cos\theta\ )$. The cutoff for angle θ is around 60° which means nearly half of the total light energy emitted by the die never leaves the interior of the package. Therefore, it can be seen that removing the package will increase the amount of light available by a factor of two.

In some situations a sun must be able to transmit (and receive) 360° to communicate with satellites that are at distances of approximately 20 meters. Currently available single LED's cannot furnish sufficient light to satisfy the requirements of intensity (light energy per unit area) at the maximum range for 360°. A typical satellite has an optical receiving surface of 10 square centimeters and must receive 10 microwatts of light energy for reliable operation and the satellite can be as much as 20 meters from the sun it communicates with.

Because of the finite size of the die in the diode, a reflecting surface of moderate size with respect to the diode

cannot focus light into a beam without divergence. However, some small amount of divergence is beneficial because it reduces the degree of alignment precision required to establish a reliable optical link between a sun and a satellite. Too much divergence, however, increases the power requirements to an uneconomic level. Generally, divergence of ± 1° is an acceptable amount.

A sun, therefore, must illuminate a band 70 centimeters in the vertical direction with a circumferential length of $1.26 \cdot 10^4$ centimeters for a total area of $8.77 \cdot 10^5$ square centimeters. Total energy required for the 360° transmission therefore is 0.877 watts. Given the rated output for a single LED, 15 LEDs are required to provide this amount of light energy.

A parabola is the desired curve to focus the light. The die of the diode must be at the focal point of the parabola. However, because there are multiple diodes there must be multiple focal points. The simplest implementation to satisfy this condition is a truncated cone coaxial with a focal ring having the dies of the LEDs centered on the focal ring.

Additionally, it is desirable to direct as much light as possible from the diodes horizontally into a narrow horizontal segment, that is, emitted rays that would not normally be in the segment should be reflected into the segment.

The position of the LEDs should be such that they obscure a minimum amount of reflected light and that the electronic input leads have a minimum exposure.

There is no single configuration that completely satisfies all of the desired features. An acceptable compromise is to position the diodes such that their axes are parallel to the axis of the cone. The cone, therefore, has the curve of half of a parabola. If the cross section of the curve

of the reflecting surface is described by the equation $y^2 = 4 \cdot f \cdot x$, then a die is positioned at y = 0 and x = f, where f is the radius of the focal ring.

Fig. 28 illustrates somewhat schematically apparatus generally designated 2800 showing one preferred implementation for an array of 16 LED's 2802,2802 wherein each LED has its wall and window removed thereby making all emitted light available as output light. To minimize the effect of skew rays reflecting from the focusing surface, the diodes are as close together as possible in a focal ring generally designated 2804 with a radius R.

Fig. 29 illustrates schematically a cross section view of the apparatus of Fig. 28 taken along line 29-29 showing generally a reflecting surface 2900 and a diode 2802. Surface 2900 is covered with a reflective film made of gold, silver, or some other material that has a high reflectance (99+ %) at the wavelength of the infra-red light, nominally 800 nanometers emitted by the die of the LED. The reflecting surface 2900 is a parabola and is generated by revolving the parabola about axis 2902. The resultant surface 2900 can be visualized as a truncated cone 2910. The focal ring radius R is defined by the size and number of LED's in the array. The LEDs' axes 2904,2904 lie in a circle defined by the focal ring R. The focal point 2912 of the parabola is defined by the desired relationship between the diameter 2906 and the height 2908 of the cone 2910. It is preferable to have a cone with the ratio of diameter to height as large as possible because the majority of rays that are not reflected from surface 2900 will not be received by the satellite, particularly as the distance between sun and satellite is increased.

The sun transmitter system is equipped with a window to protect the LED's and the reflective surface from contamination by particulates or tampering. An inert gas such as nitrogen contained under very slight pressure in the transmitter

system will retard effects of atmospheric corrosive elements. Such a protective enclosure is described above in connection with Fig. 15B.

Fig. 30 shows an illustrative optical system for aligning a line-of-sight path between a satellite 3000 and a sun 3002. Satellite 3000 contains a dichroic mirror 3004 which reflects light from the normal signalling light source to a lens 3008 which conveys the signals to sun 3002. For alignment purposes, a source of visible light 3010 is positioned in the same plane as normal light sources 3006 but at 90° to source 3006 such that a visible beam of light generated by source 3010 passes through mirror 3008 and should be coincident with the beam from source 3006 if both sources were operating simultaneously. Consequently, a visible light beam is propagated along the same path as the normal light signals and a person aligning the sun and satellite can visually determine when the light path is on target.

What is claimed is:

1. In a local area network having a data communication device which is connectable to said network, a first optical transceiver connected to said network for transferring information from said first transceiver to said network, a second optical transceiver connected to said data communication device for transferring information from said data communication device to said second transceiver, means for establishing a free space optical transmission path between said first transceiver and said second transceiver to create a first data stream from said data communication device to said network, the improvement comprising:

means in said second transceiver for inserting first control information for controlling said optical transmission path into said first data stream; and

means in said first transceiver responsive to said first control information for removing said first control information from said first data stream so that said control information is not transmitted to said network.

2. In a local area network, the improvement according to Claim 1 wherein a second data stream is created from said network to said data communication device and said first transceiver comprises means for inserting second control information to control said optical transmission path into said second data stream for transmission to said second transceiver and wherein said second transceiver comprises means for removing said second control information from said second data stream so that said second control information is not transmitted to said data communication device to establish a bi-directional communication link between said data communication device and the network.

3. In a local area network, the improvement according to Claim 2 wherein said first transceiver further comprises means responsive to said first control information received from said second transceiver for inserting a predetermined portion of said first control information into said second data stream for retransmission back to said second transceiver.

4. In a local area network, the improvement according to Claim 3 wherein said predetermined portion of said second data stream comprises a coded preamble transmitted before data in said data stream.

5. In a local area network, the improvement according to Claim 3 wherein said second transceiver comprises means responsive to said predetermined portion of said first control information received from said first transceiver for comparing said predetermined portion of said first control information with a corresponding portion of said first control information and means for interrupting said first data stream if said predetermined portion and said corresponding portion are not equivalent.

6. In local area network, the improvement according to Claim 2 wherein said first transceiver inserts a predetermined code in said second data stream and said second transceiver further comprises means for generating a predetermined interval of time and means responsive to said predetermined code for interrupting said first data stream if said predetermined code is not received within said time interval.

7. In a local area network, the improvement according to Claim 5 wherein said second transceiver further comprises means for forwarding an error signal to said data communication device if said predetermined code is not received within said time interval.

8. In a local area network, the improvement according to Claim 2 wherein said first transceiver comprises means responsive to optical power transmitted from said second transceiver over said optical transmission path for generating a power level signal and means responsive to said power level signal for inserting a power level code into said second data stream and wherein said second transceiver further comprises means responsive to said power level code for adjusting said optical power transmitted from said second transceiver over said optical transmission path.

9. In a local area network, the improvement according to Claim 1 further comprising means for physically mounting said second transceiver near said data communication device.

10. In a local area network, the improvement according to Claim 9 wherein said mounting means comprising a mounting track that allows said second transceiver to be positioned at a plurality of selected locations near said data communication device.

11. A local area communication network for transferring code digital information comprising a protocol defined preamble and data between said network and a data communication device, said network comprising;

a first optical transceiver connected to said network for transferring said coded digital information between said first optical transceiver and said network;

a second optical transceiver connected to said data communication device for transferring said coded digital information between said data communication device and second optical transceiver;

means for establishing a free space optical transmission path between said first optical transceiver and said second optical transceiver so that a first data stream carrying said coded digital information from said data communication device to said network and a second data stream carrying said coded digital information from said network to said data communication device are created;

means in said second optical transceiver for modifying said protocol defined preamble to provide a first optical preamble by inserting first control information into said first optical preamble in said first data stream;

means in said first optical transceiver responsive to said first control information for removing said first control information from said first optical preamble in said first data stream so that said first control information is not transmitted to said network;

means in said first optical transceiver responsive to said first control information for controlling said second data stream;

means in said first optical transceiver for modifying said protocol defined preamble to provide a second optical preamble by inserting second information into said second

optical preamble of said second data stream for transmission to said second optical transceiver, and

means in said second optical transceiver for removing said second control information from said second data stream so that said second control information is not transmitted to said data communication device.

12. A local area network according to Claim 11 wherein said first optical preamble received at said first optical transceiver is inserted into said second data stream for retransmission to said second optical transceiver.

13. A local area network according to Claim 12 wherein said second optical transceiver comprises means responsive to a predetermined portion of said second optical preamble received from said first optical transceiver for comparing said predetermined portion of said second optical preamble with a corresponding portion of said first optical preamble sent to said first optical transceiver and means for interrupting said first data stream if said predetermined portion and said corresponding portion are not equivalent.

14. A local area network according to Claim 13 wherein said first optical transceiver inserts a predetermined heartbeat code into said second optical data stream and said second transceiver further comprises means for generating a predetermined interval of time, and means responsive to said heartbeat code for interrupting said first data stream if said heartbeat code is not received within said time interval.

15. A local area network according to claim 14 wherein said second optical transceiver further comprises means for forwarding an error signal to said data communication device if said heartbeat code is not received within said time interval.

16. A local area network according to Claim 15 wherein said first optical transceiver comprises means responsive to optical power transmitted from said second optical transceiver over said optical transmission path for generating a power level signal and means responsive to said power level signal for inserting a power level code into said second data stream and wherein said second optical transceiver further comprises means responsive to said power level code for adjusting said optical power transmitted from said second optical transceiver over said optical transmission path.

17. In a local area network, the improvement according to Claim 11 further comprising means for physically mounting said second optical transceiver near said data communication device.

18. In a local area network, the improvement according to Claim 17 wherein said mounting means comprises a mounting track that allows said second optical transceiver to be positioned at a plurality of selected locations near said data communication device.

19. In a local area network having a data communication device which is connectable to said network, a first optical transceiver connected to said network, a second optical transceiver connected to said data communication device and means for establishing a free space optical transmission path between said first optical transceiver and said second optical transceiver, an improved optical transceiver comprising;

a laser diode for generating high output power optical signals for transmission to another optical transceiver;

means responsive to said high output power optical signals for diffusing said high output power optical signals to produce diffused optical signals so that said diffused optical signals are not dangerous to view directly.

20. In a local area network, the improved optical transceiver according to Claim 19 wherein said diffusing means comprises a conical reflector having an axis and a surface, said surface being generated by revolving a section of a parabola with an axis perpendicular to said reflector axis around said reflector axis.

21. In a local area network, the improved optical transceiver according to Claim 20 wherein said diffusing reflector is comprises to a metallized, vacuum-molded plastic material.

22. In a local area network, the improved optical transceiver according to Claim 19 wherein said diffusing means comprises an optical fiber having a diameter and a length sufficient to diffuse said optical signals.

23. In a local area network, the improved optical transceiver according to Claim 19 further comprising an optical detector and means for focusing diffuse optical signals received from another transceiver onto said optical detector.

24. In a local area network, the improved optical transceiver according to Claim 23 wherein said focusing means comprises a conical reflector having an axis and a surface which is generated by revolving a section of a parabola with an axis perpendicular to said reflector axis around said reflector axis.

25. In a local area network, the improved optical transceiver according to Claim 24 wherein said focusing reflector is comprised of a metallized, vacuum-molded plastic material.

26. A local area communication network comprising;

a plurality of data communication devices which are connectable to said network;

a first optical transceiver connected to said network;

a plurality of second optical transceivers, each of said plurality of second optical transceivers being connected to one of said plurality of data communication devices, and

means for establishing a free space optical transmission path with a plurality of separate transmission channels between said first optical transceiver and said plurality of second optical transceivers, said first optical transceiver communicating with each of said plurality of second optical transceivers in at least one of said plurality of channels.

27. A local area communication network according to Claim 26 wherein said plurality of separate transmission channels are established by transmitting and receiving optical signals at a single frequency unique to each channel.

28. A local area communication network according to Claim 26 wherein said plurality of separate transmission channels are established by transmitting optical signals at a first single frequency unique to each channel and receiving optical signals at a second single frequency unique to each channel.

29. A local area communication network according to Claim 26 wherein said plurality of separate transmission channels are established by transmitting and receiving optical signals by modulating a single carrier frequency common to all of said plurality of channels with a modulation frequency which is unique to each channel.

30. In a local area network having a data communication device which is connectable to said network, a first optical transceiver connected to said network, a second optical transceiver connected to said data communication device and means for establishing a free space optical transmission path between said first optical transceiver and said second optical transceiver, an improved light source for an optical transceiver comprising:

light emitting means for generating high power optical signals for transmission to another optical transceiver, and

means responsive to said light emitting means for focusing said high power optical signals into a light beam for transmission in a 360° pattern.

31. In a local area network, the improved light source of a optical transceiver according to claim 30 wherein said focusing means comprises a truncated cone having an axis and a reflective surface, said surface being generated by revolving a section of a parabola with an axis perpendicular to said truncated cone axis, said surface coinciding with a curve defined by half of said parabola.

32. In a local area network, the improved light source for an optical transceiver according to claim 31 wherein said light emitting means comprise a plurality of LEDs circumaxially disposed about said truncated cone axis, each of said LEDs having an axis parallel to said truncated cone axis and coinciding with a focal ring defined by the focal point of said parabola defining said truncated cone reflective surface to cause light emitted from said LEDs to be focused in a narrow horizontal segment along said truncated cone reflective surface.

33. In a local area network, the improved light source for an optical transceiver according to claim 32 wherein said truncated cone reflective surface comprises a reflective film having a high reflectance of at least 99%.

34. In a local area network, the improved light source for an optical transceiver according to claim 32 wherein LEDs are unpackaged LEDs.

35. In a local area network having a data communication device which is connectable to said network, a first optical transceiver connector to said network, a second optical transceiver connected to said data communication device and means for establishing a free space optical transmission path between said first optical transceiver and said second optical transceiver, an improved optical transceiver comprising:

a plurality of light sources for transmitting optical signals;

means for coupling a first optical diffusion element to said plurality of light sources for receiving said optical signals from said plurality of light sources, said coupling means comprising fiber optic elements, and

a first conical reflector having an axis and a surface, said surface being generated by revolving a section of a parabola with an axis perpendicular to said conical reflector axis around said conical reflector axis; said first conical reflector surface focusing diffuse optical signals from said first optical diffusion element and reflecting said focused optical signal radially from said surface and normal to said conical reflector axis.

36. In a local area network, the improved optical transceiver according to claim 35 further comprising:

a plurality of optical detectors;

means for coupling a second optical diffusion element to said plurality of optical detectors, said coupling means comprising fiber optic elements, and

a second conical reflector having an axis and a surface, said surface being generated by revolving a section of a parabola with an axis perpendicular to said conical reflector axis around said conical reflector axis, said second conical reflector surface focusing diffuse optical signal received from another transceiver onto said second optical diffusion element.

37. In a local area network, the improved optical transceiver according to claim 36 further comprising said first and second conical reflectors being arranged such that a base of each is in contact with the other and said axis of each conical reflector is co-extensive with one another.

38. In a local area network, the improved optical transceiver according to claim 37 further comprising: said first conical reflector having a first focal circle defined by the loci of focal points of said parabolic surface of said first conical reflector;

said second conical reflector having a second focal circle defined by the loci of focal points of said parabolic surface of said second conical reflector;

a first cylindrical lens coaxial with said first conical reflector axis and coincident with said first focal circle for focusing and transmitting said focused optical signals reflected from said first conical reflector; and

a second cylindrical lens coaxial with said second conical reflector axis and coincident with said second focal circle for focusing diffuse optical signals received from another transceiver onto said second conical reflector surface.

39. In a local area network having a data communication device which is connectable to said network, a first optical transceiver connected to said network, a second optical transceiver connected to said data communication device and means for establishing a free space optical transmission path between said first optical transceiver and said second optical transceiver, an improved optical transceiver comprising:

a plurality of light sources for transmitting optical signals;

a first optical diffusion element;

means for coupling said plurality of light sources to said first optical diffusion element, said coupling means comprising first, fiber optic elements;

a first cylindrical lens focusing diffuse optical signals and transmitting said focused optical signals in a radial direction normal to the longitudinal axis of said first cylindrical lens, and

means for coupling diffuse optical signals from said first optical diffusion element to said first cylindrical lens, said coupling means comprising second fiber optic elements.

40. In a local area network, the improved optical transceiver as defined in claim 39 further comprising:

a plurality of optical detectors;

a second optical diffusion element;

means for coupling said plurality of optical detectors to said second optical diffusion element, said coupling means comprising third fiber optic elements;

a second cylindrical lens for focusing diffuse optical signals received from another optical transceiver, and means for coupling said second cylindrical fourth fiber optic elements.

41. In a local area network having a data communication device which is connectable to said network, a first optical transceiver connected to said network, a second optical transceiver connected to said data communication device and means for establishing a free space optical transmission path between said first optical transceiver and said second optical transceiver, an improved optical transceiver comprising:

a plane/parabolic reflector having a reflective surface, said reflective surface having a parabolic contour in two dimensions and being flat in a third dimension and a focus line coincident with and defined by the loci of the focal points of said parabolic reflective surface.

42. In a local area network, the improved optical transceiver according to claim 41 further comprising at least one optical detector located along said focus line, said plane/parabolic reflector focusing diffuse optical signals received from another transceiver onto said at least one optical detector.

43. In a local area network, the improved optical transceiver according to claim 42 wherein each of said at one optical detector and said at least one light source include color filters to produce optical signals having different wavelengths so that an optical detector receiving light transmitted from more than one light source only detects those optical signals transmitted from a light source producing the same wavelength optical signal.

44. In a local area network having a data communication device which is connectable to said network, a first optical transceiver connected to said network, a second optical transceiver connected to said data communication device and means for establishing a free space optical transmission path between said first optical transceiver and said second optical transceiver, an improved optical transceiver comprising:

a first fiber optic element having a first and second end;

a first lens for focusing diffuse optical signals received from another transceiver onto the first end of the fiber optic element;

light detector means located remotely from said first lens and coupled to the second end of said first fiber optic element for receiving said focused optical signals;

a second fiber optic element having a first and second end, one end being coupled to a light source for transmitting optical signals, and

a second lens located remotely from said light source for focusing diffuse optical signals, said second end of said fiber optic element being in alignment with said second lens to impinge the transmitted optical signals onto said second lens.

45. In a local area network having a data communication device which is connectable to said network, a first optical transceiver connected to said network, a second optical transceiver connected to said data communication device and means for establishing a free space optical transmission path between said first optical transceiver and said second optical transceiver, an improved optical transceiver comprising:

a first lens for focusing diffuse optical signals;

a second lens for focusing diffuse optical signals;

a flat reflector located remotely from and in line-of-view with said first and second lens and at a 45° thereto, said flat reflector reflecting diffuse optical signals received from another transceiver onto said first lens, said flat reflector reflecting toward another transceiver focused optical signals transmitted from said second lens,

a first fiber optic element having one and coupled to said first lens for receiving and conducting said focused diffused optical signals received from said another transceiver, and

a second fiber optic element having one end coupled to said second lens for coupling to said second lens, diffuse optical signals to be transmitted to another transceiver.

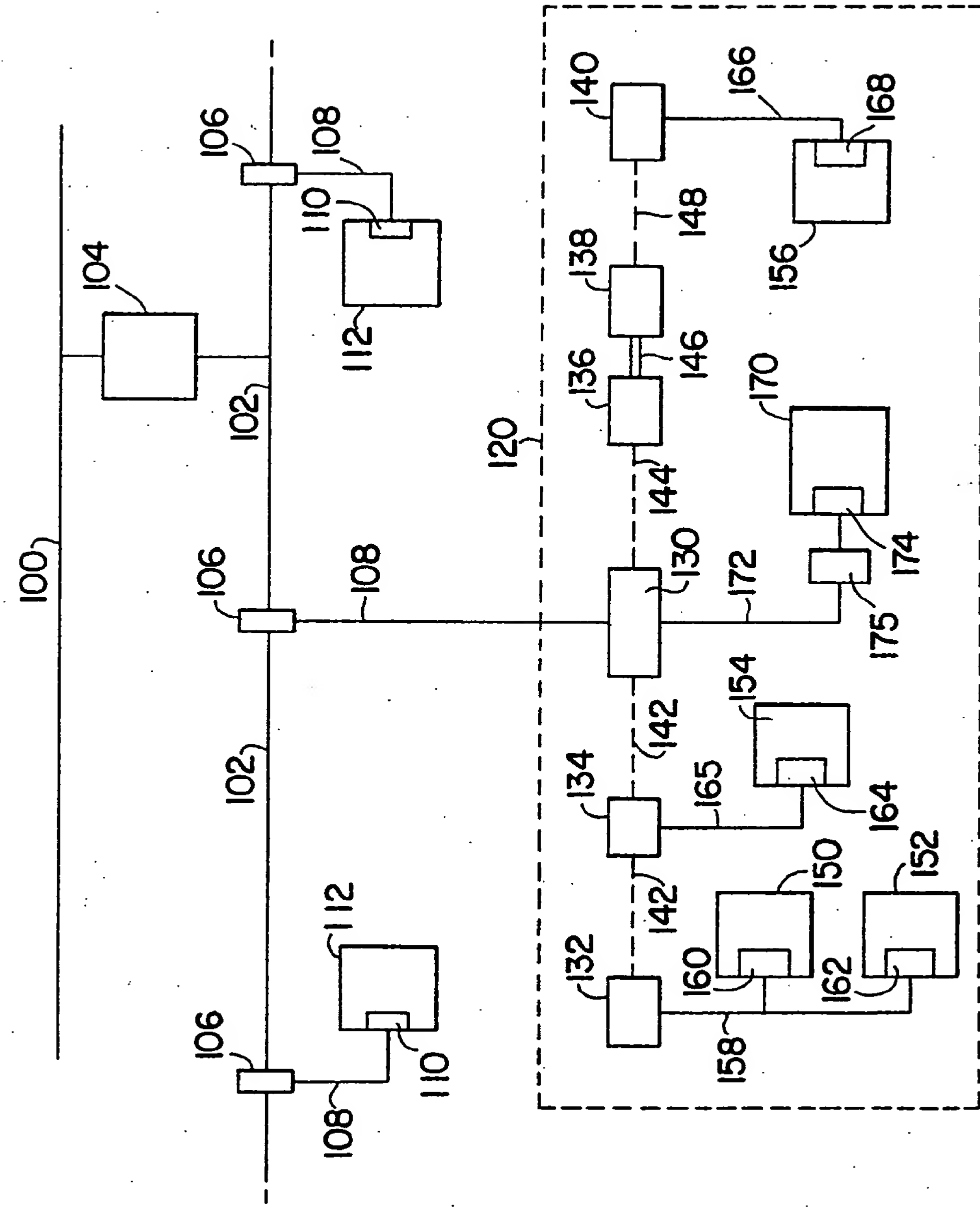
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FIG. 1

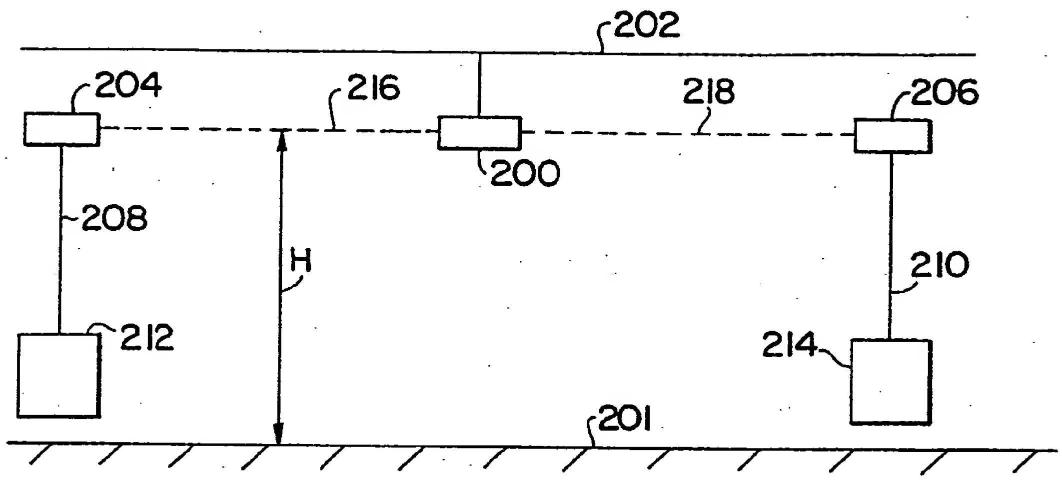
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FIG. 2

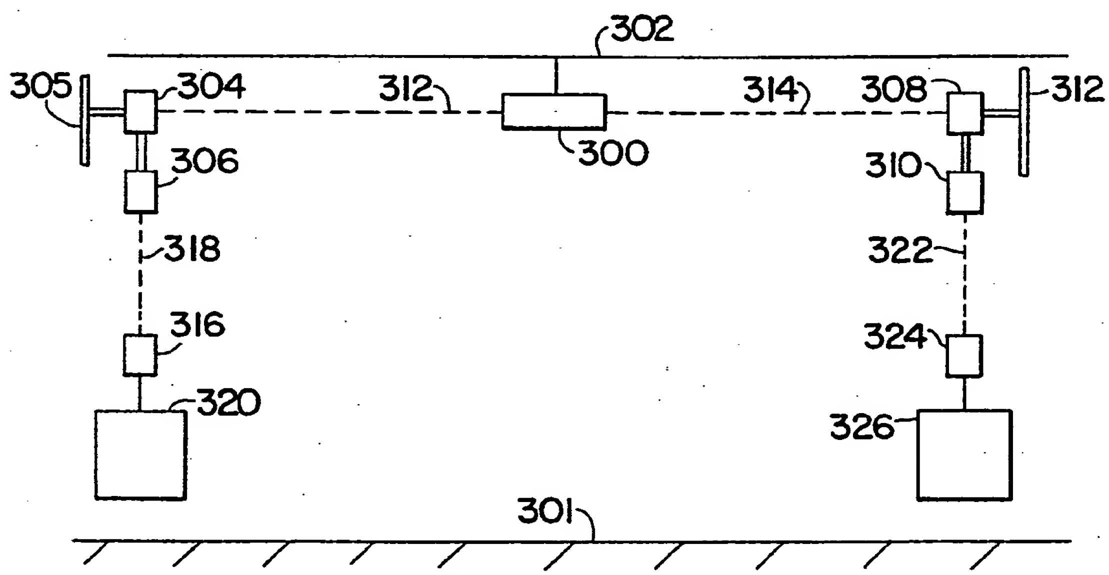
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FIG. 3

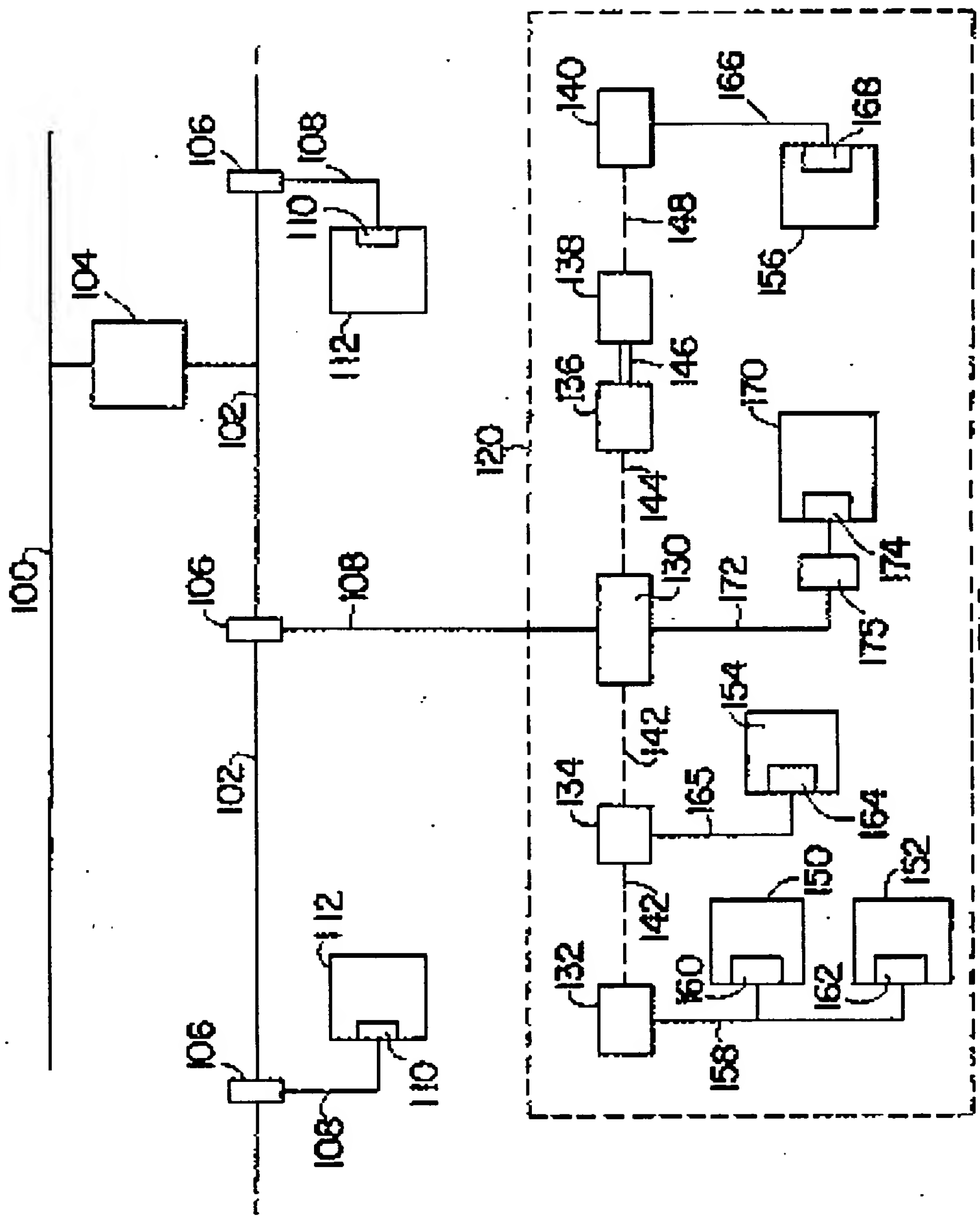
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FIG. 1

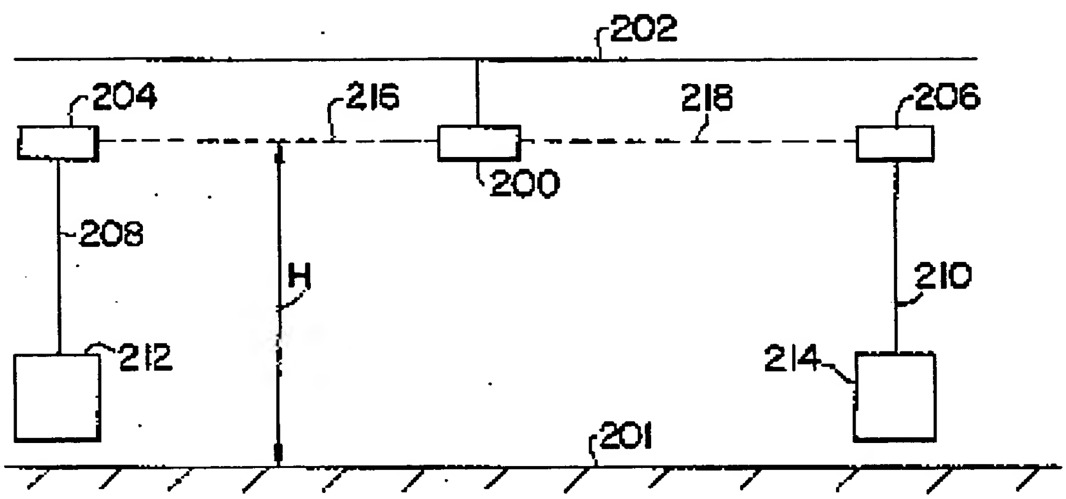
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FIG. 2

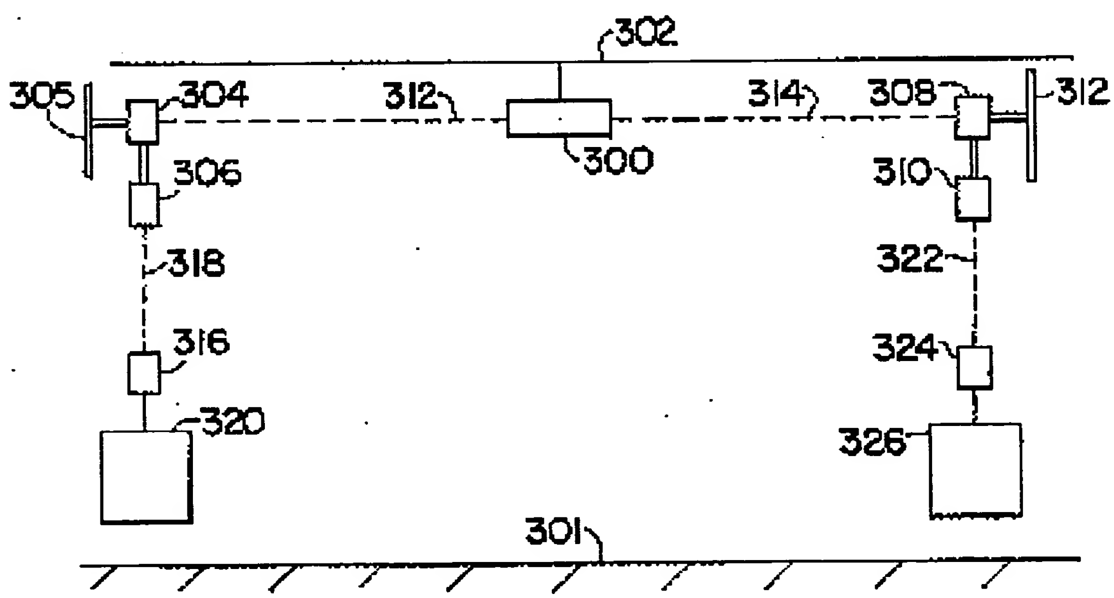
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FIG. 3

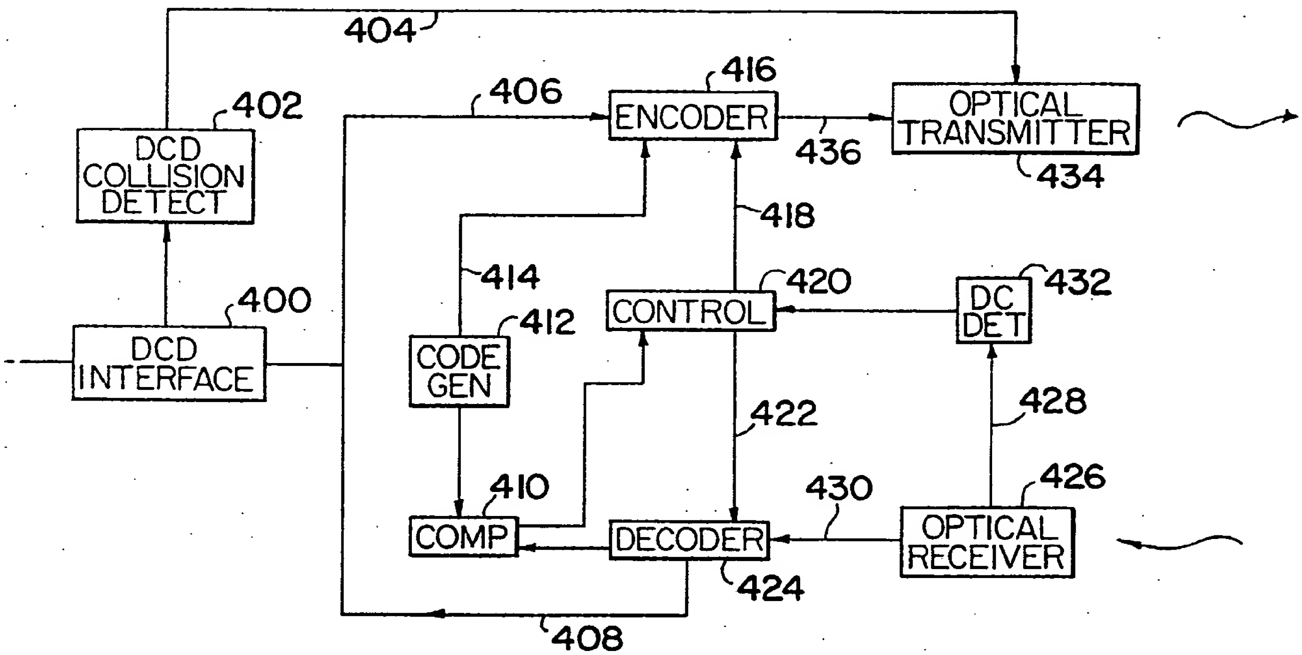


FIG. 4

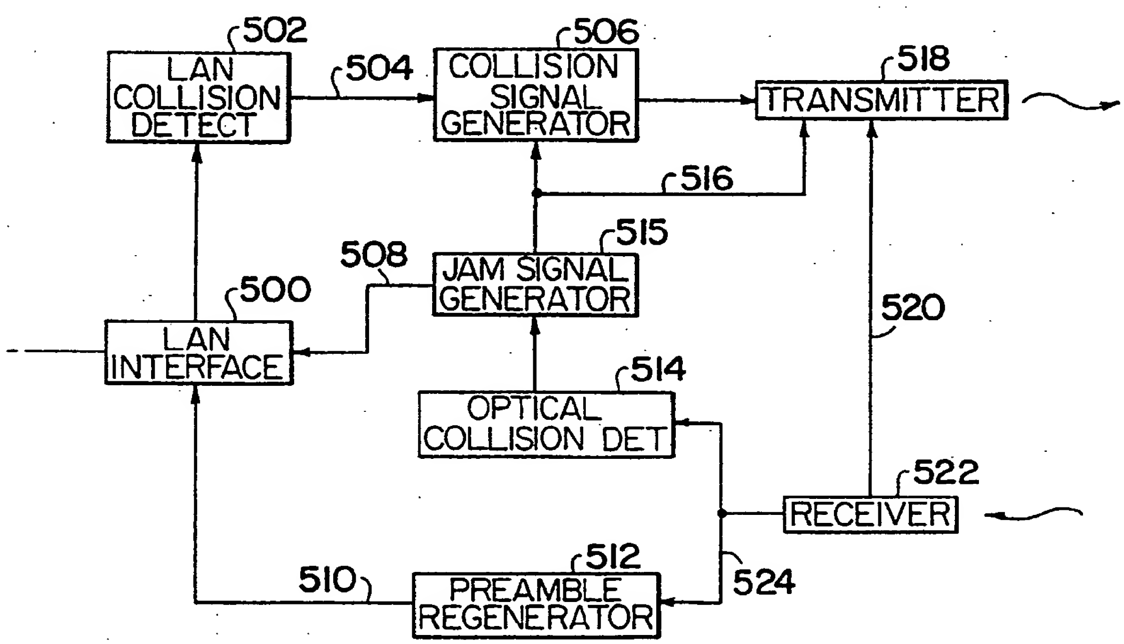
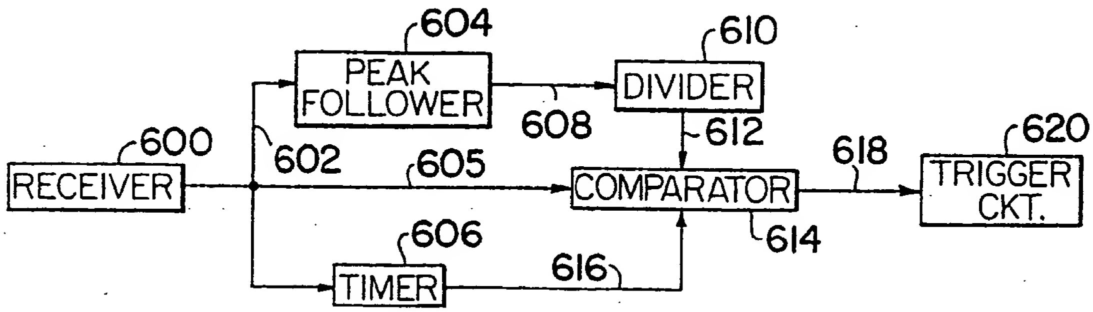


FIG. 5

SUBSTITUTE SHEET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PEAK FOLLOWER
610
DIVIDER
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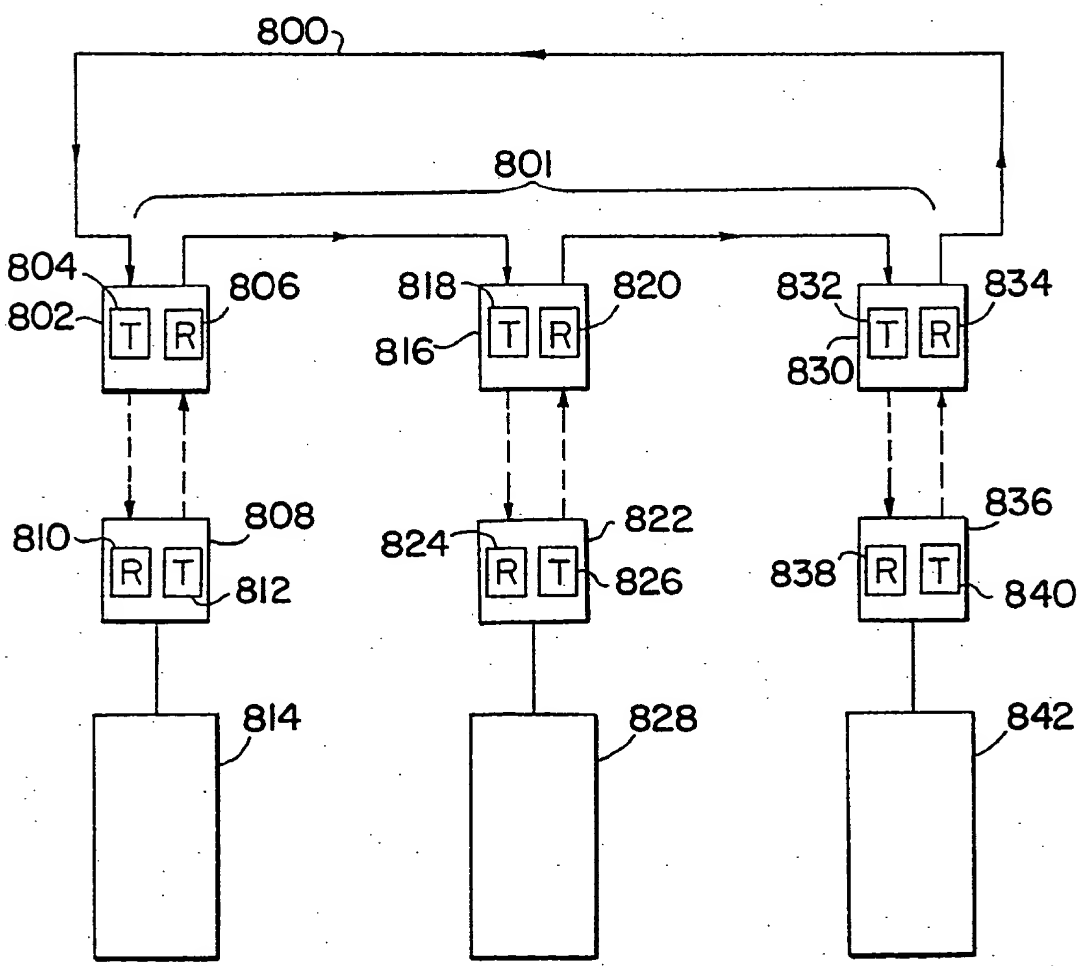
612
600
RECEIVER
602
605
COMPARATOR
618
620
TRIGGER CKT.
606
TIMER
616
614

FIG. 6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814
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842

FIG. 8

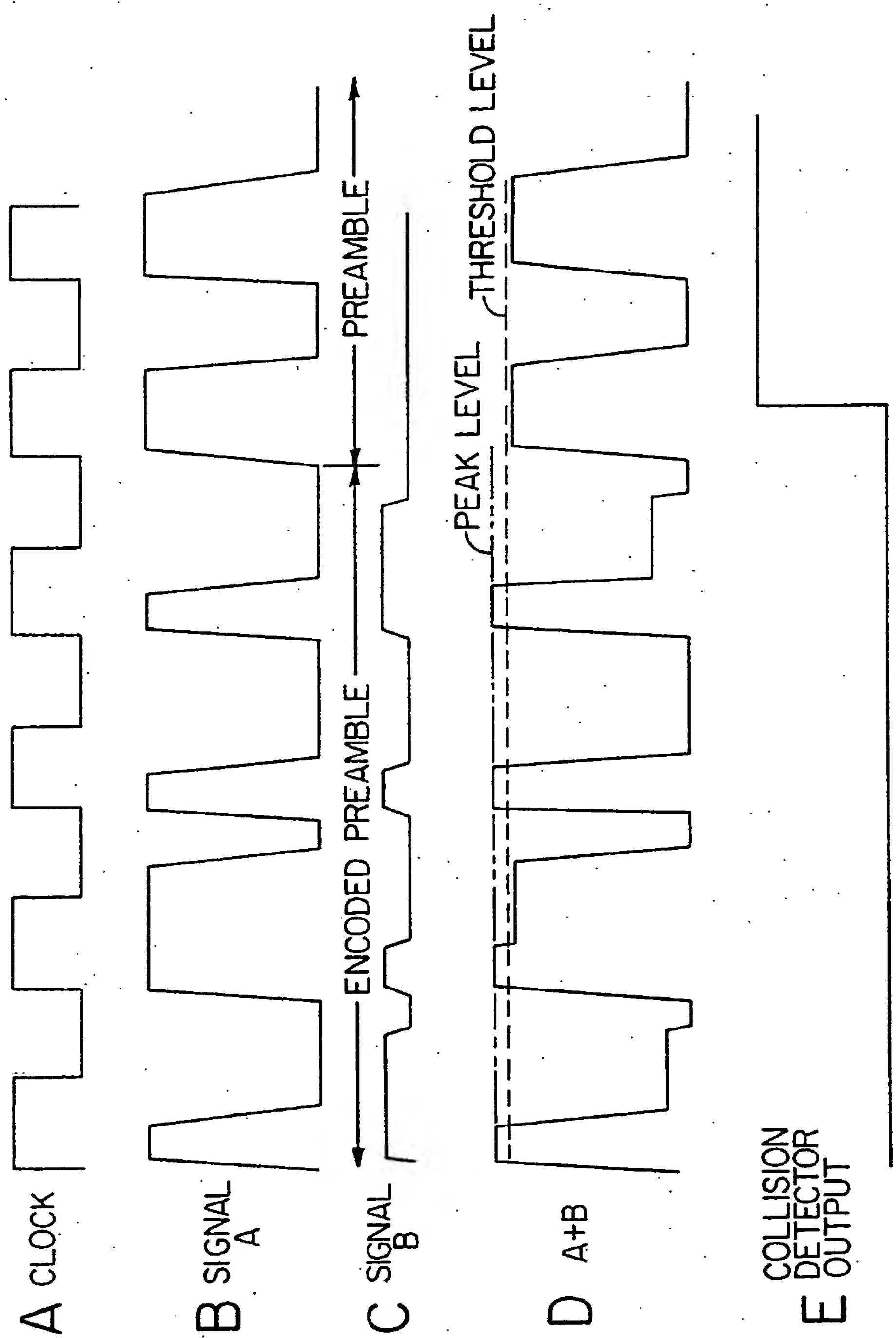

A CLOCK
B SIGNAL A
C SIGNAL B
D A+B
E COLLISION DETECTOR OUTPUT
PREAMBLE
ENCODED PREAMBLE
PEAK LEVEL
THRESHOLD LEVEL

FIG. 7

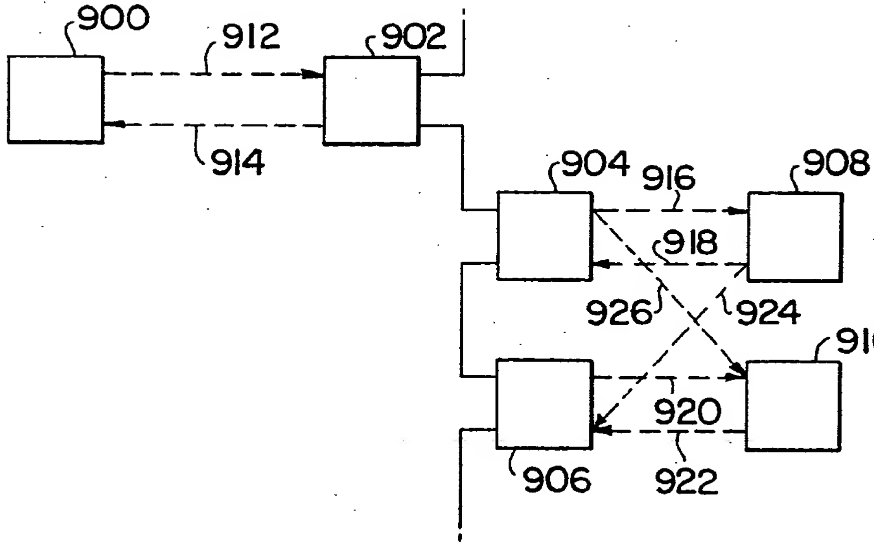


FIG. 9

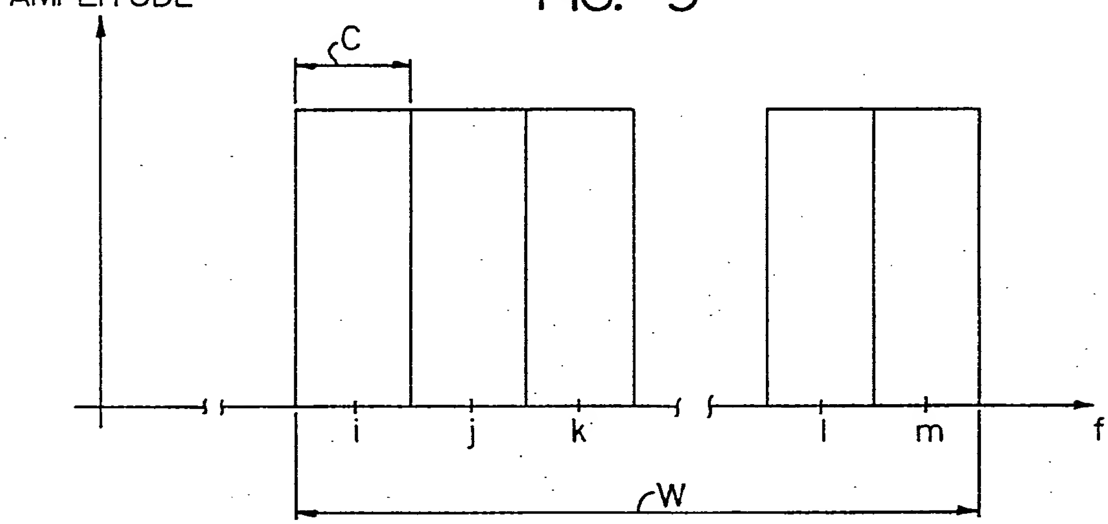


FIG. 10

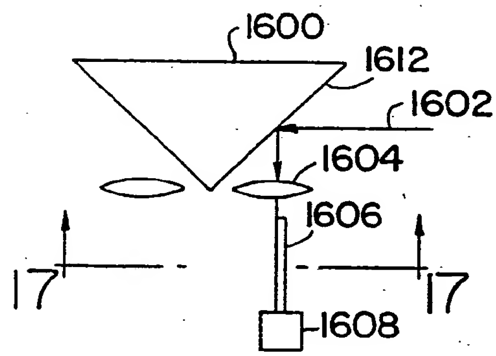


FIG. 16

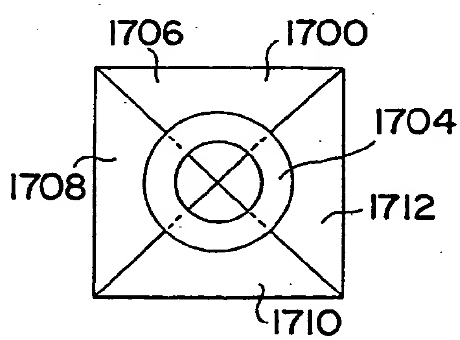
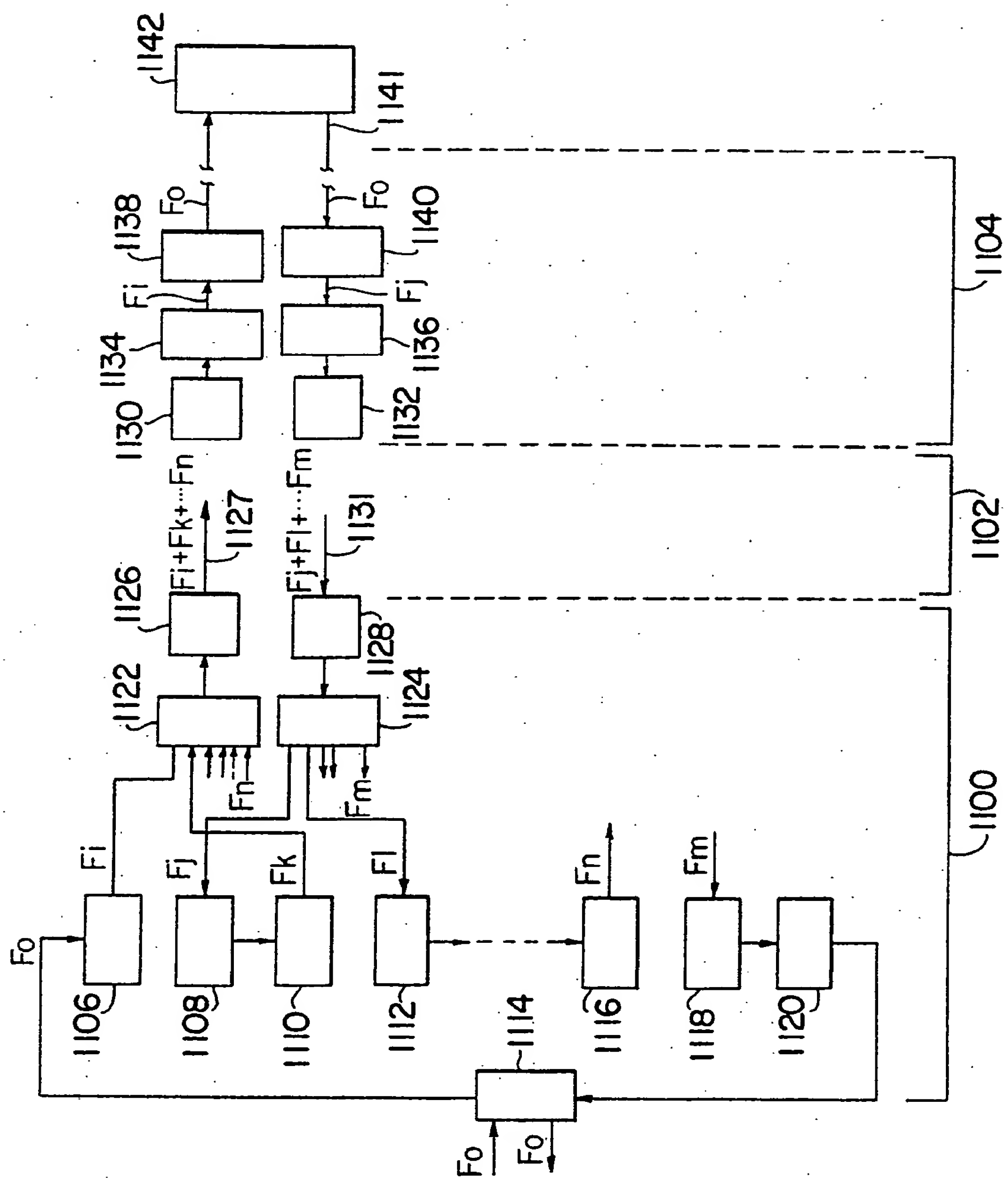


FIG. 17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1131
Fj+Fl+···Fm
1128
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Fi
Fj
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1118
1120
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FIG. 11

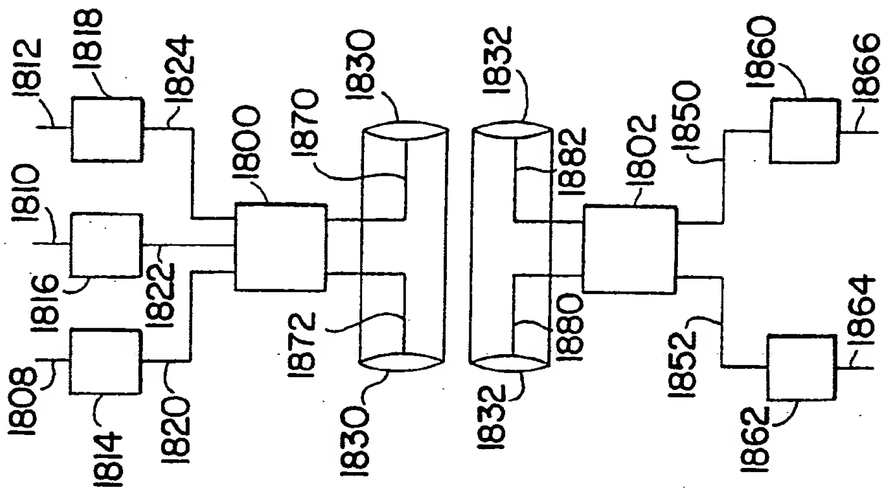
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FIG. 18

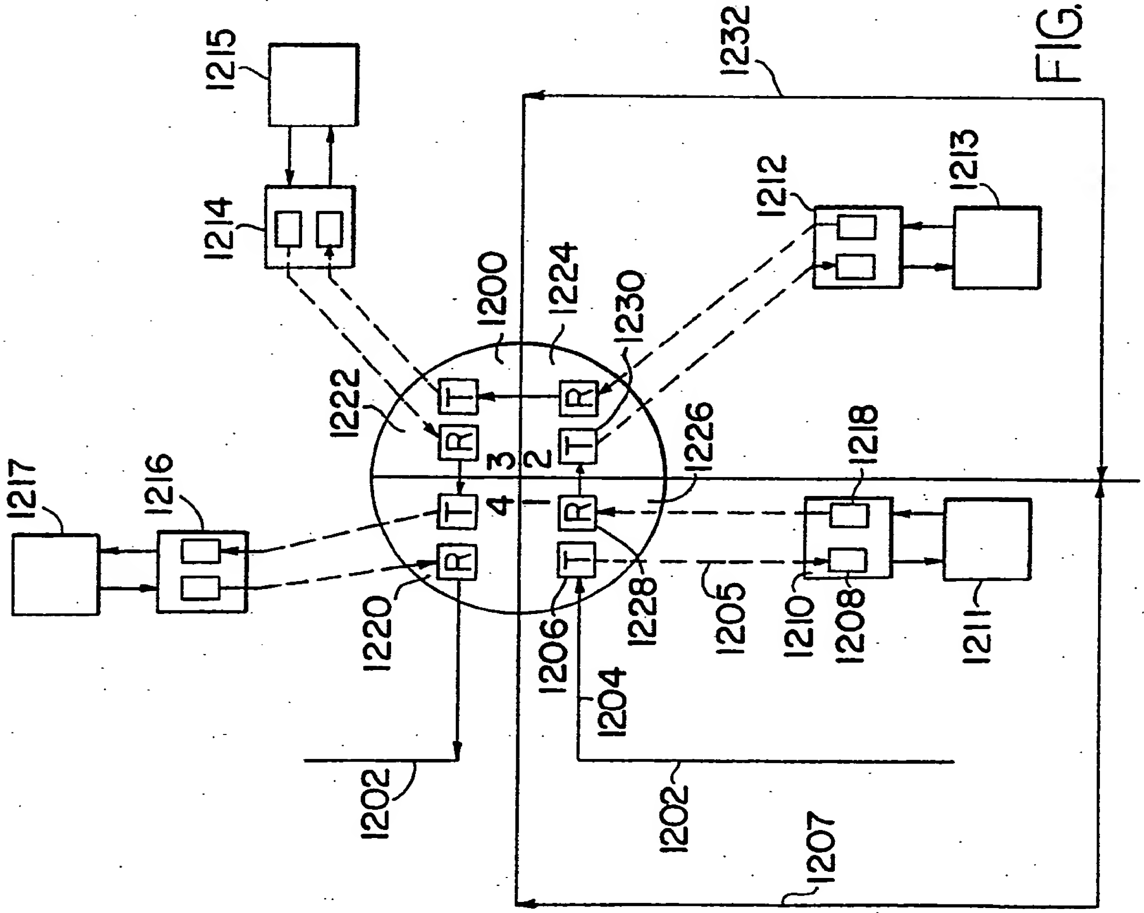
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FIG. 12

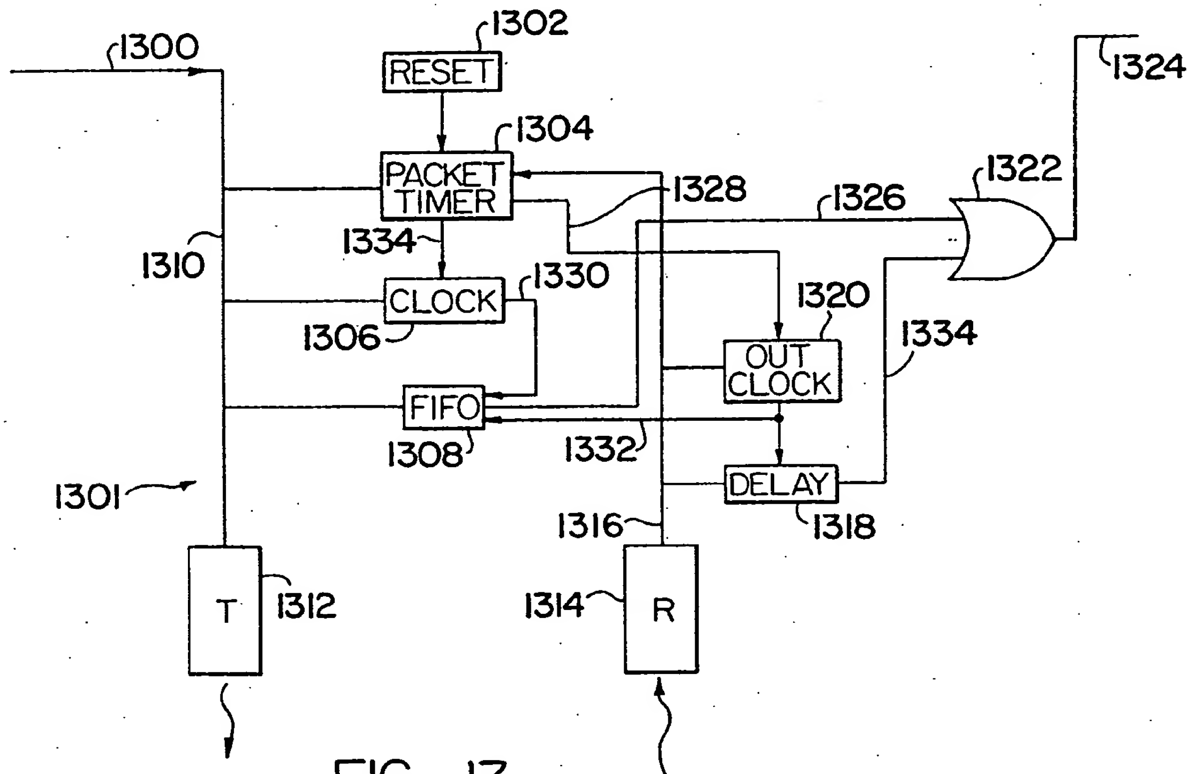

FIG. 13

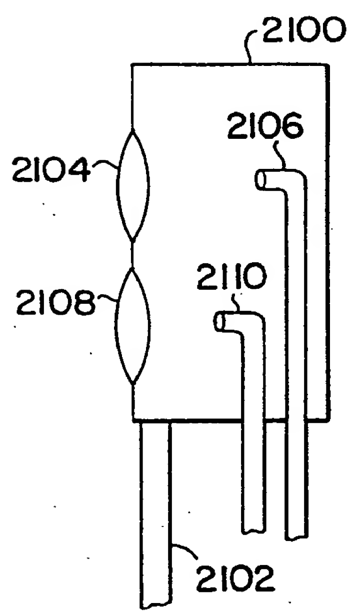

FIG. 21

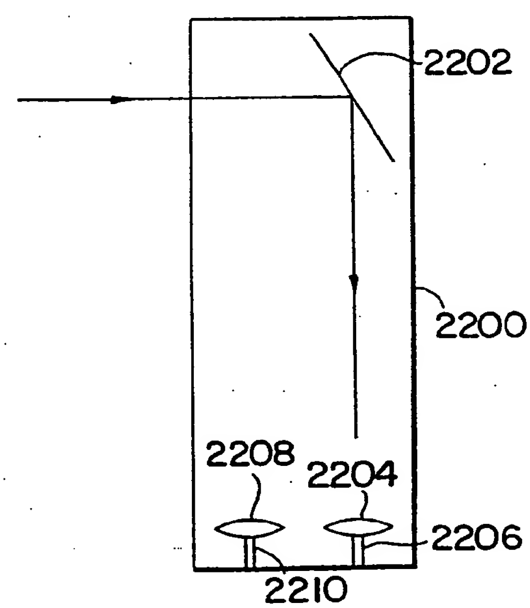

FIG. 22

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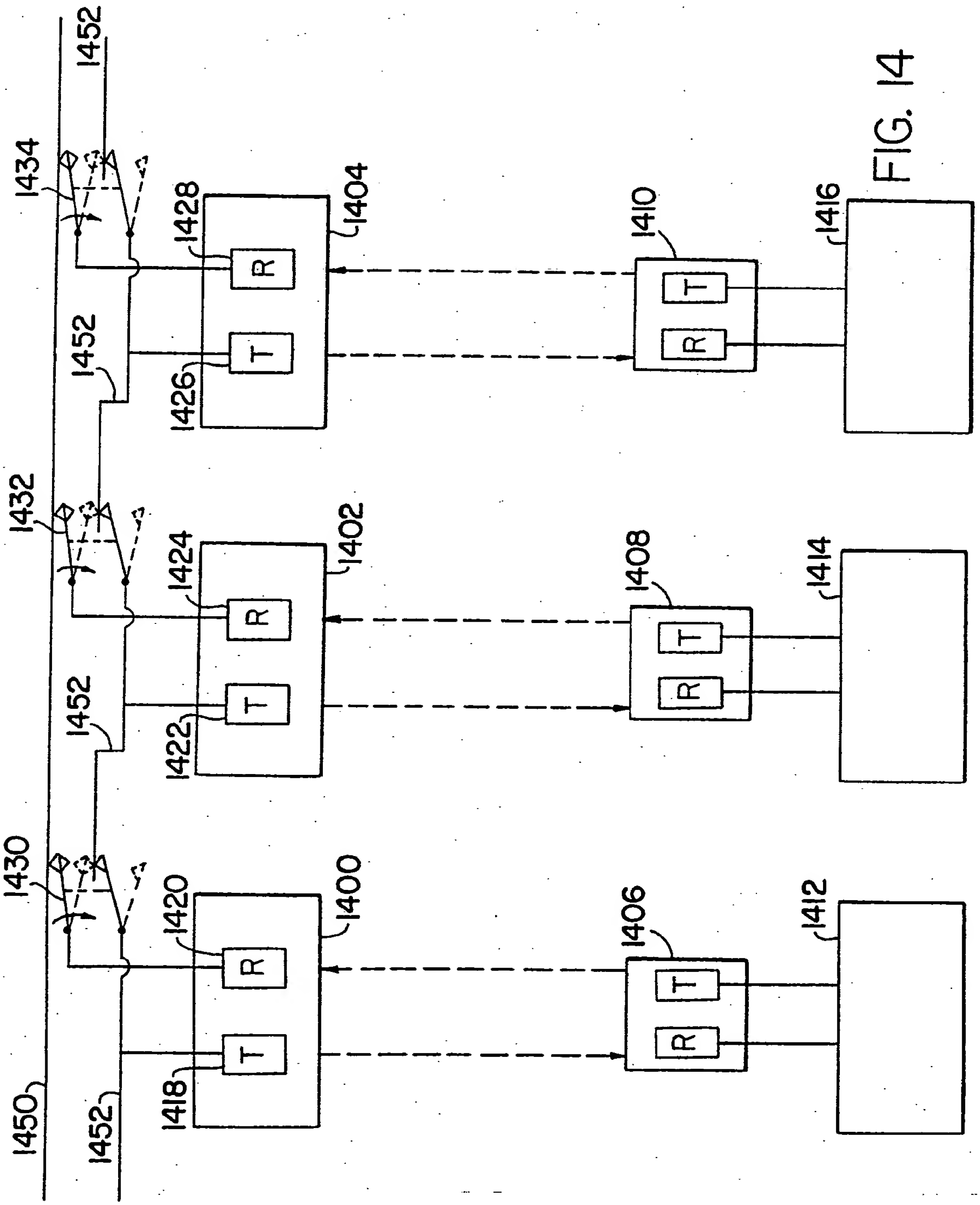
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FIG. 14

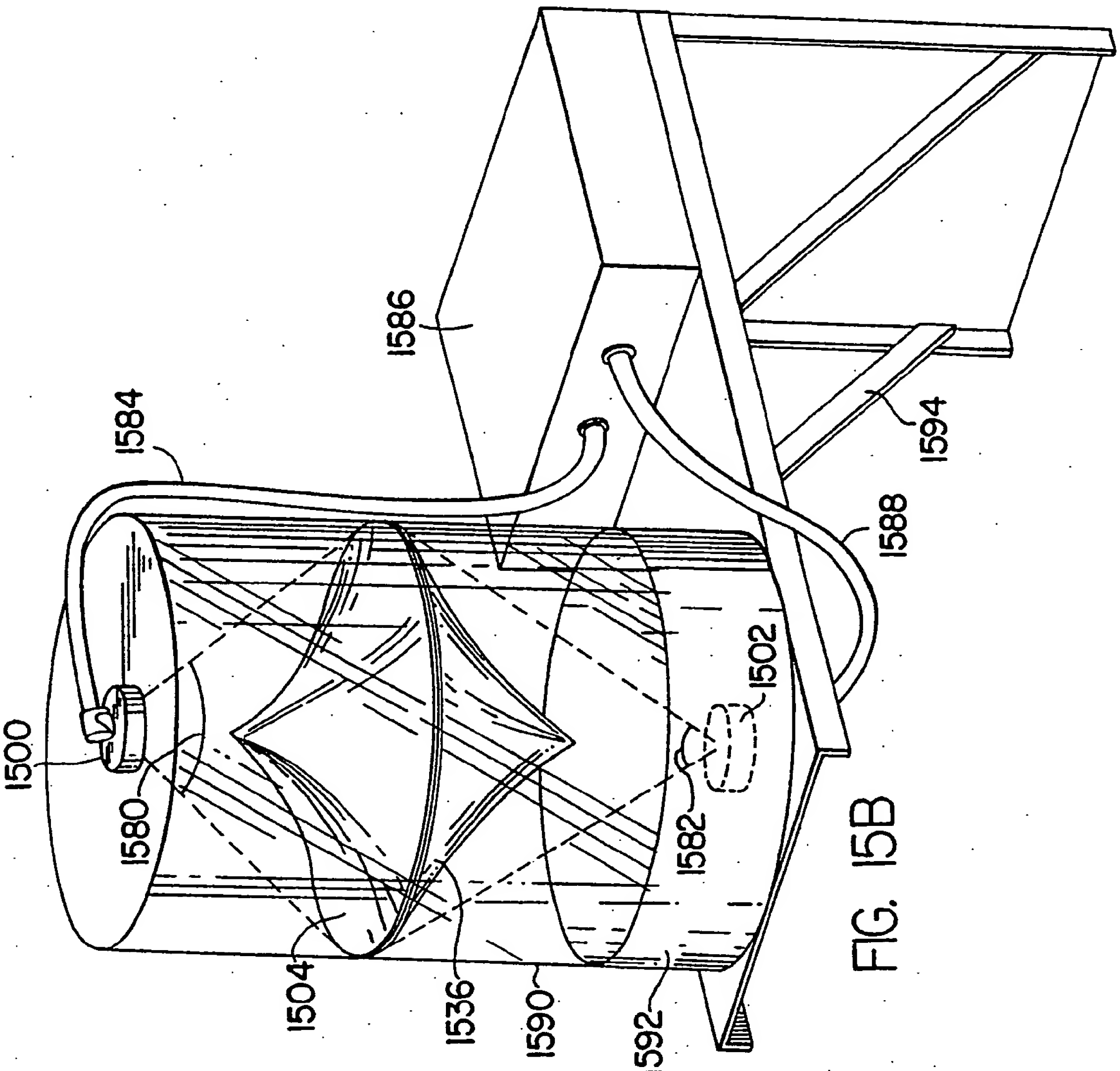

FIG. 15B

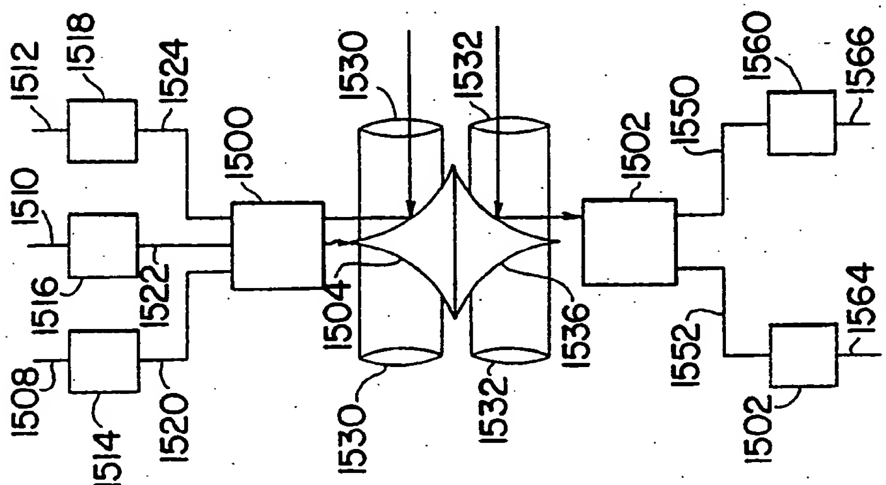

FIG. 15A

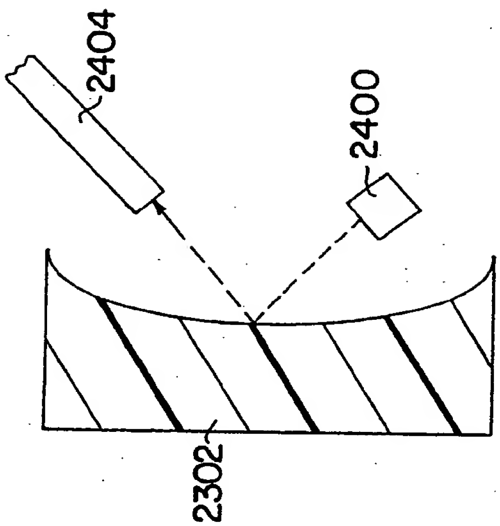

FIG. 24

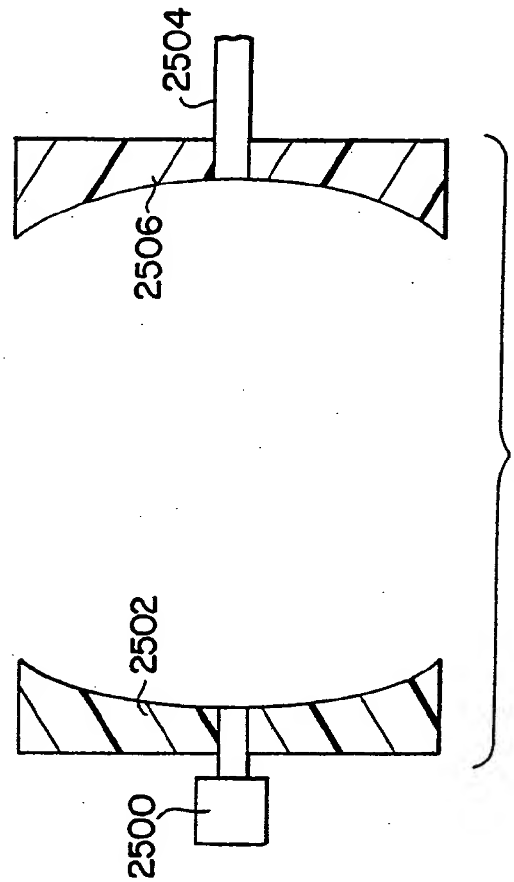

FIG. 25

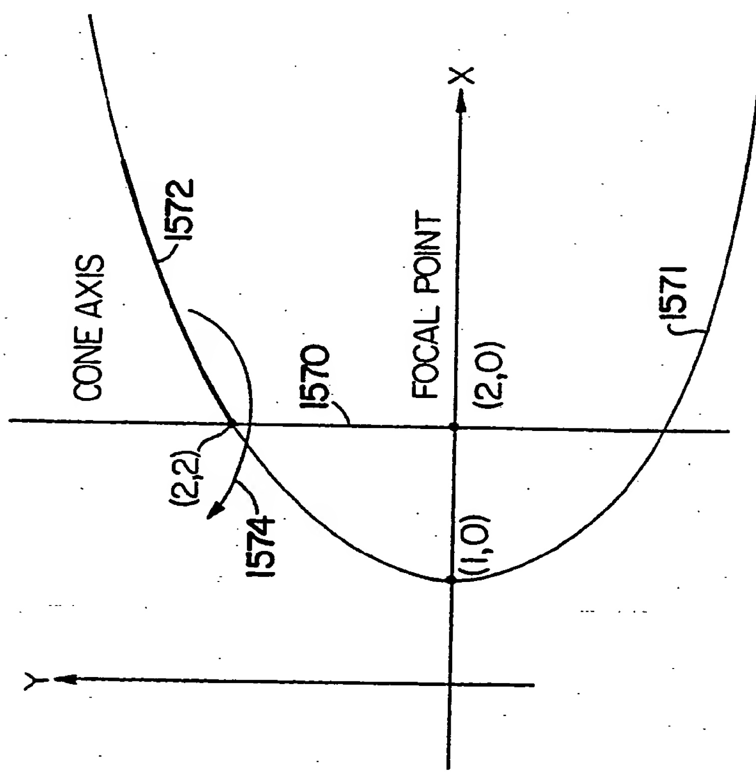

FIG. 15C

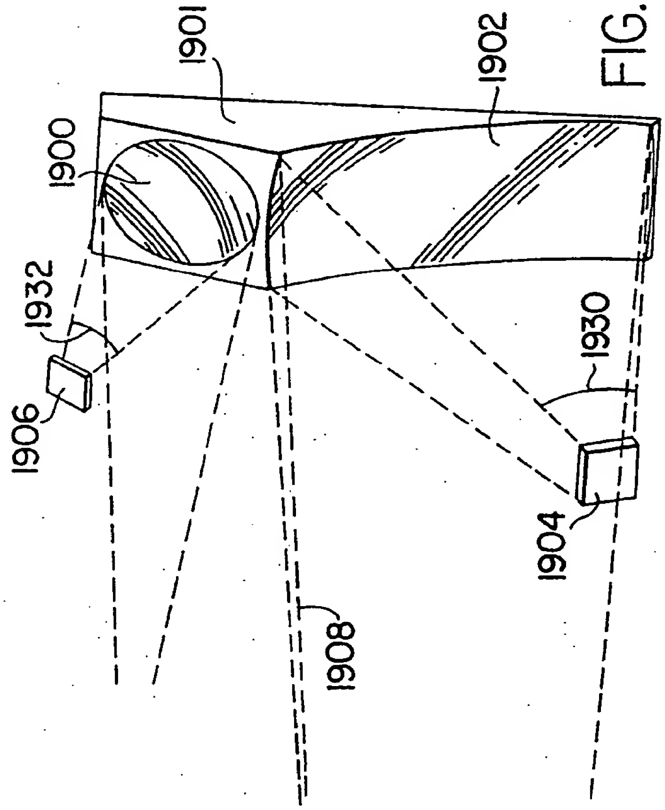

FIG. 19A

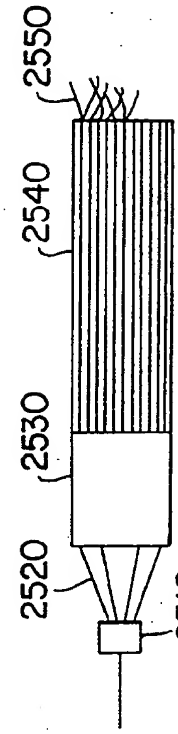

FIG. 25A

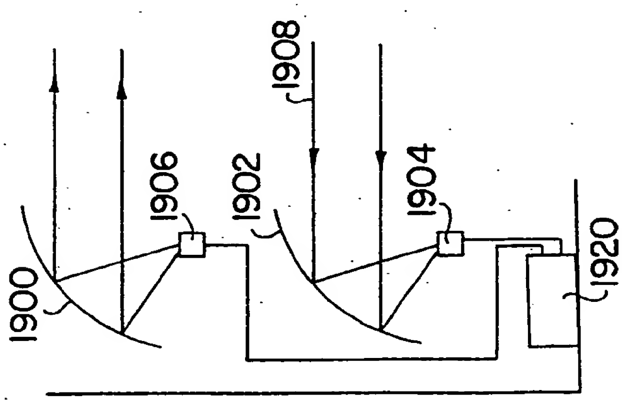

FIG. 19

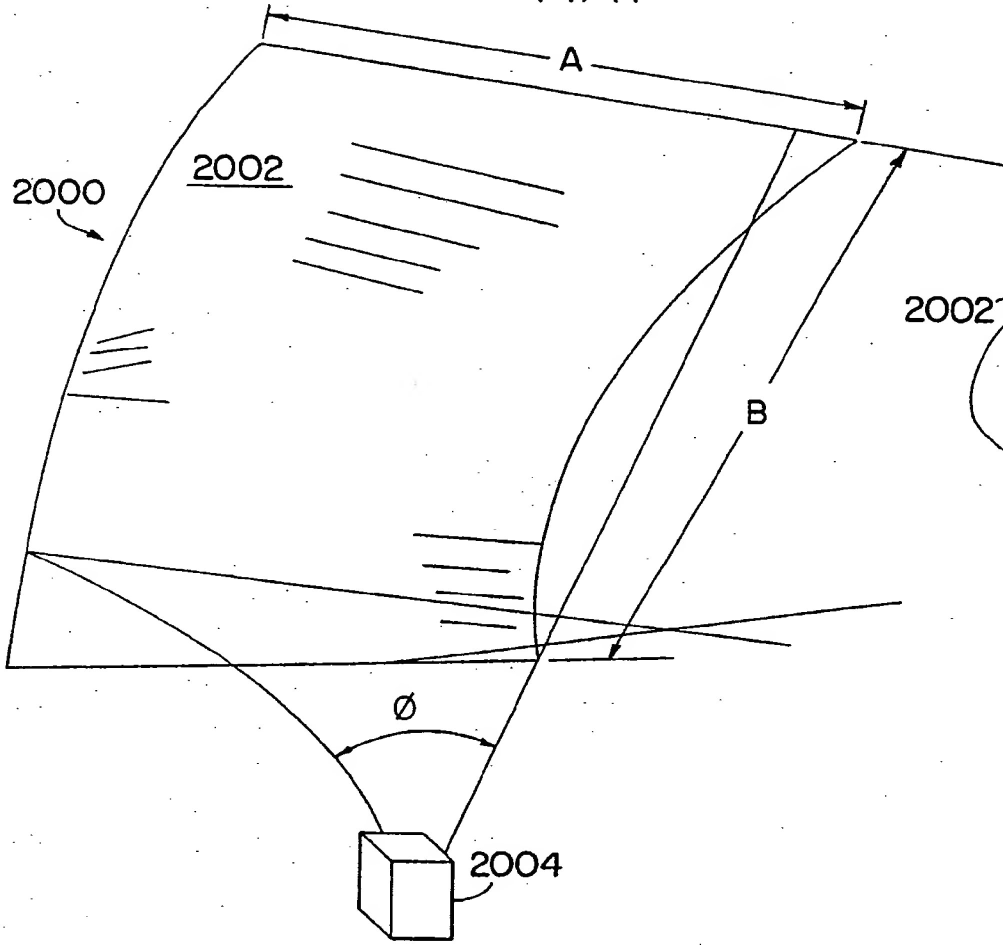

FIG. 20A

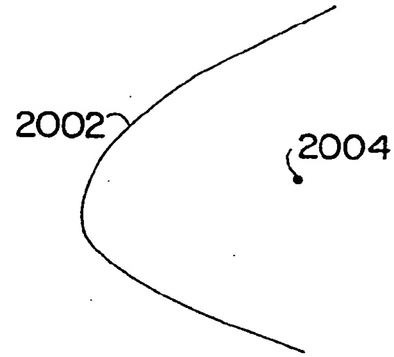

FIG. 20D

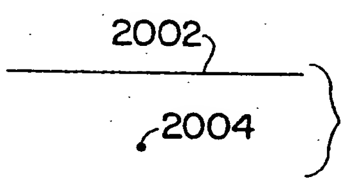

FIG. 20B

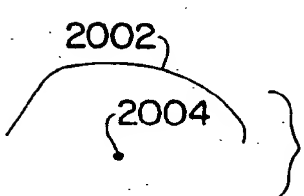

FIG. 20C

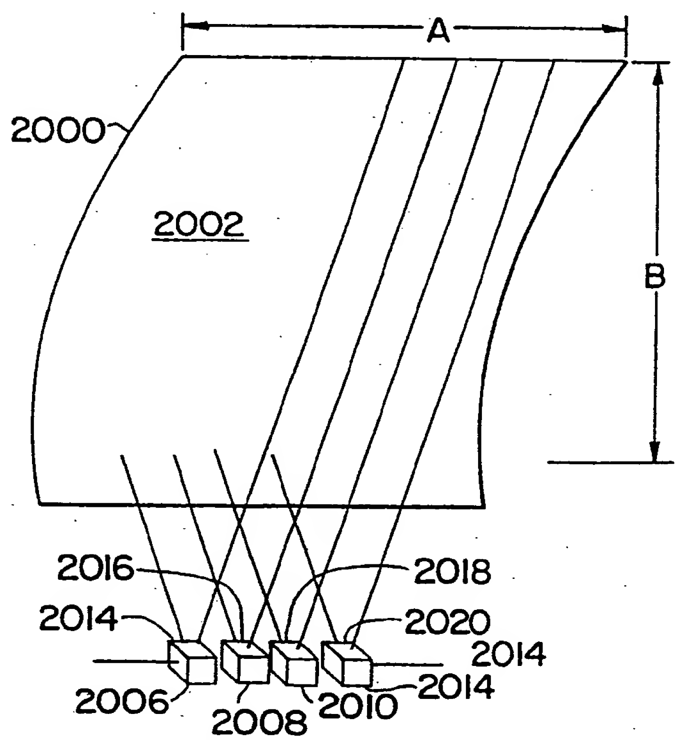

FIG. 20E

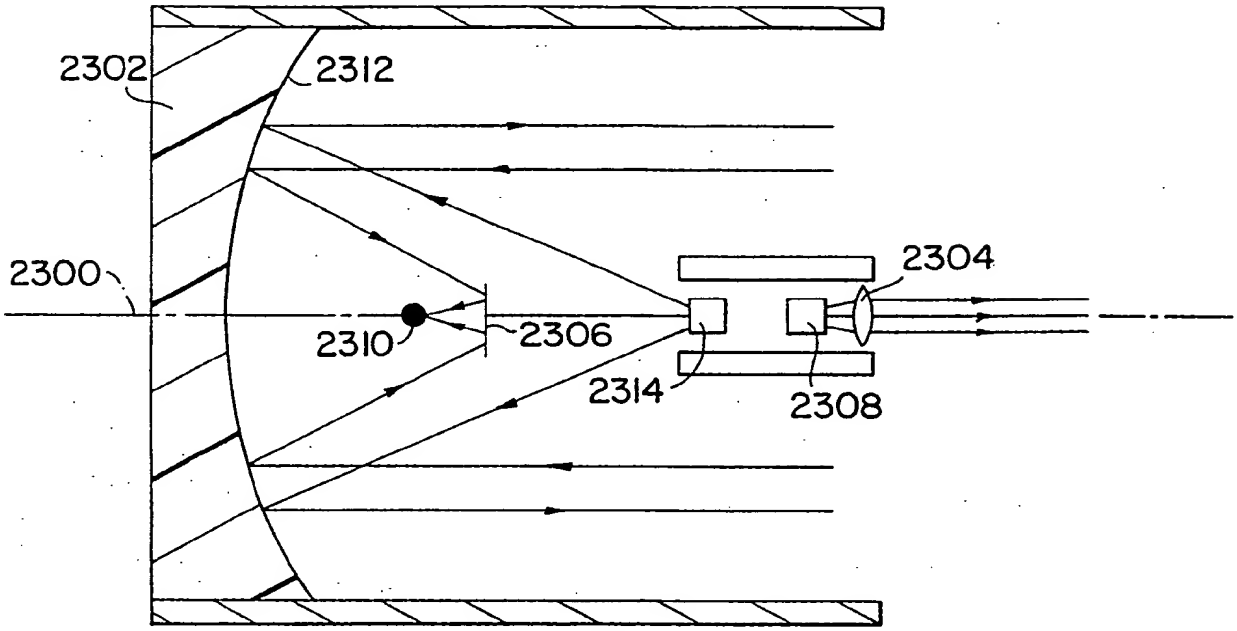
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FIG. 23

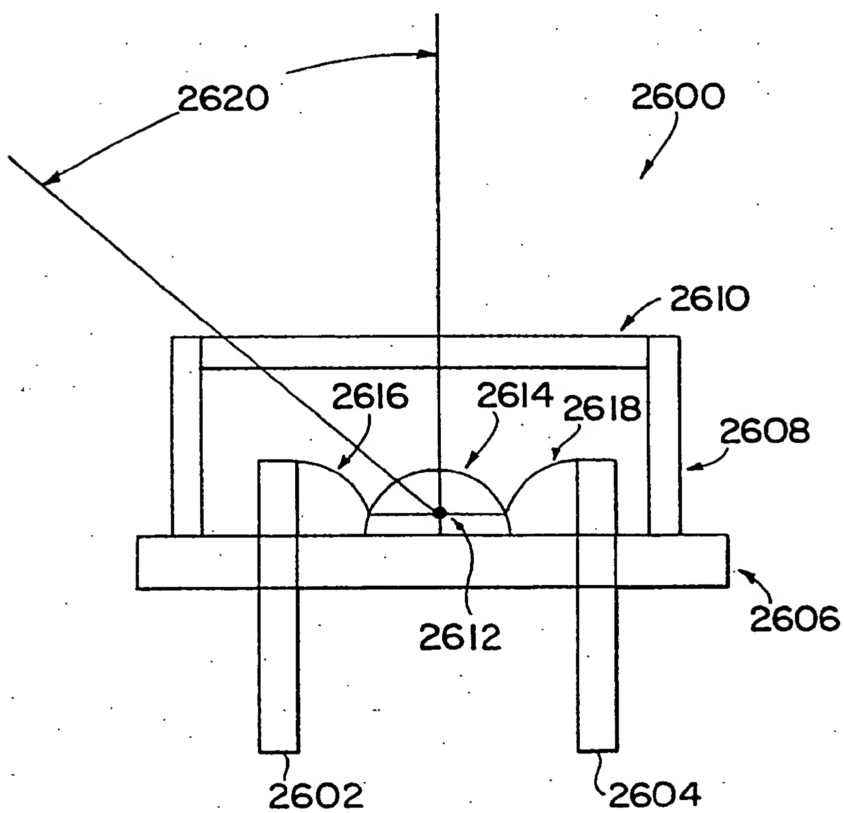
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FIG. 26

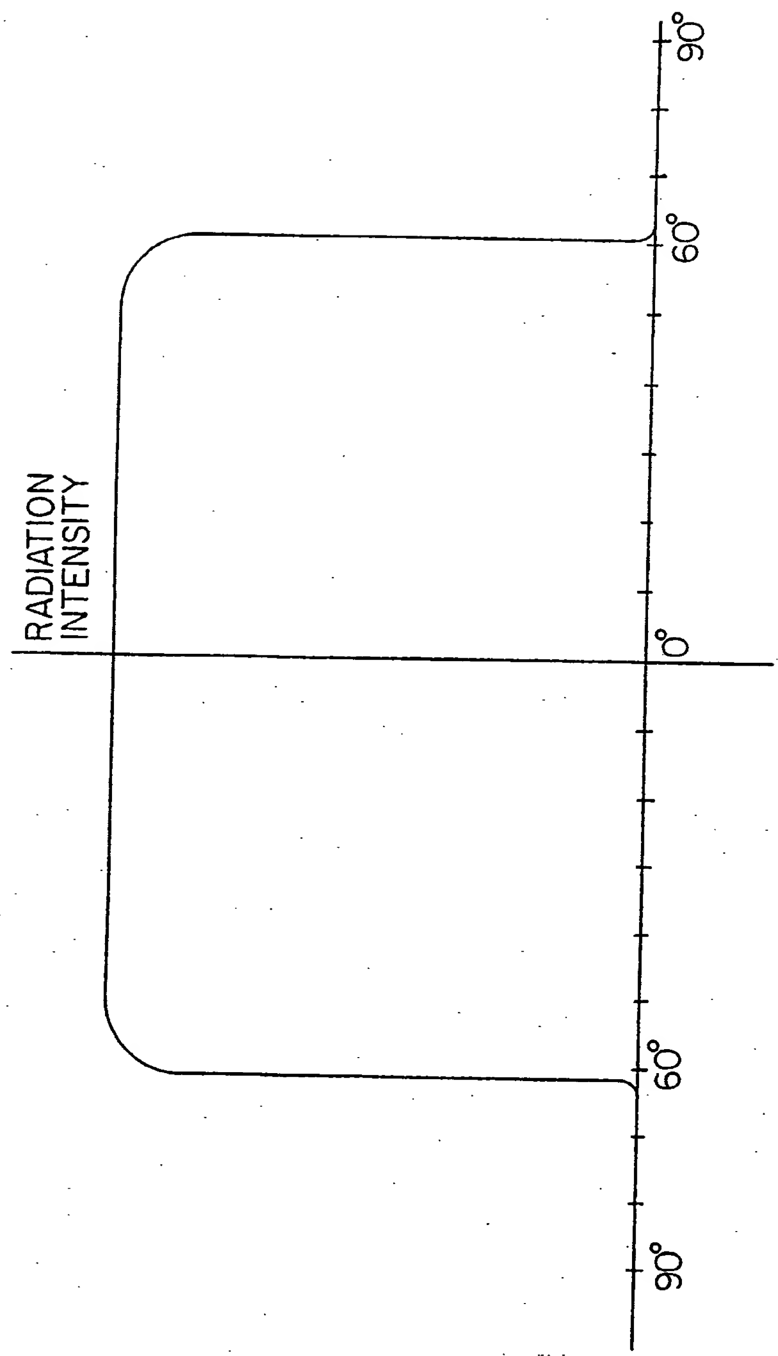

FIG. 27

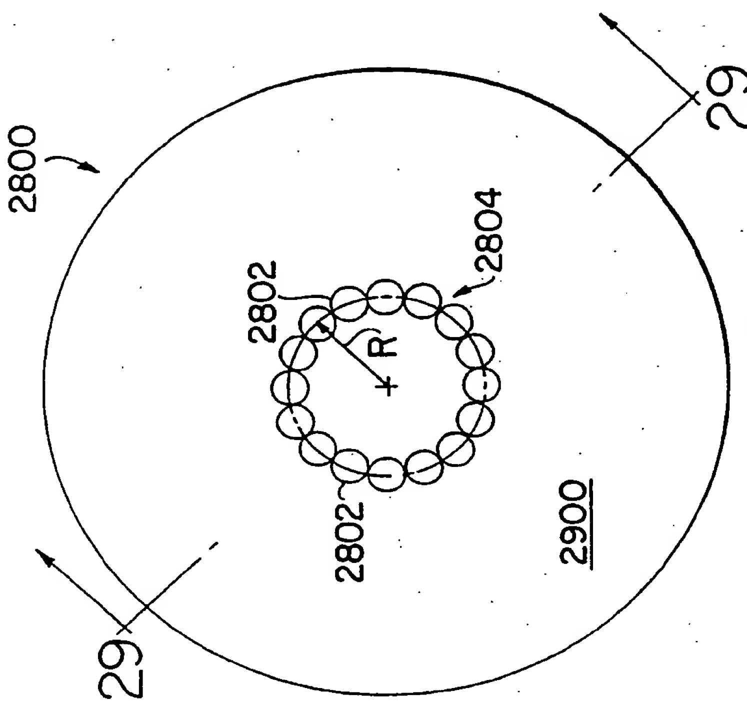

FIG. 28

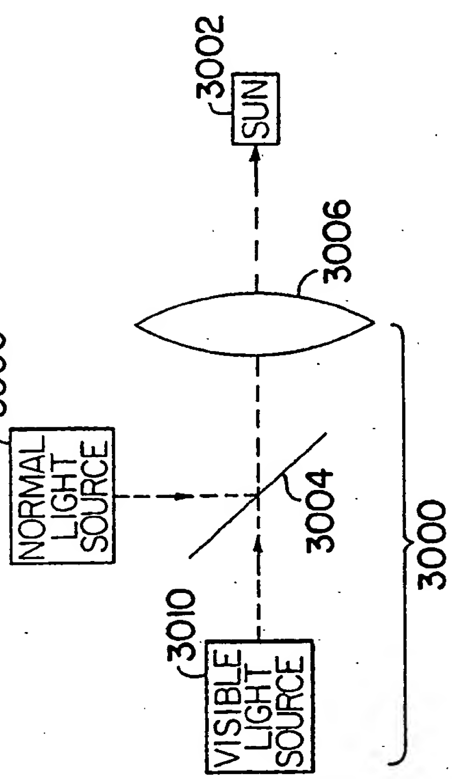

FIG. 30

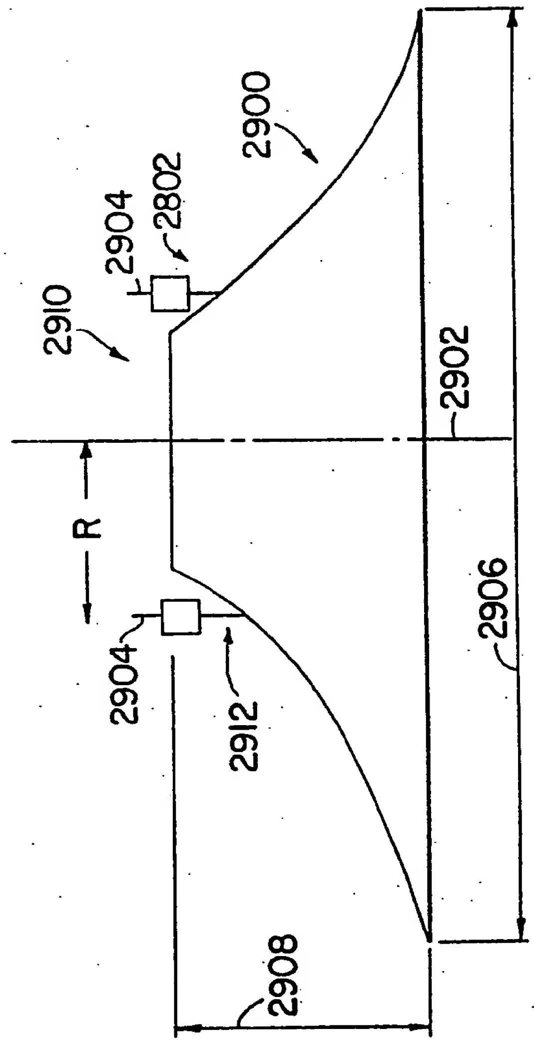

FIG. 29

INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/07515

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5) H04B 10/24, H04B 10/10 H04J 14/08
US CL 455/606,607 370/4

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
US CL	455/606,607,617 370/4,85.3,94.1

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	US, A, 4,665,519 (KIRCHNER ET AL) 12 MAY 1987 See claims 14-15.	1-7,11-15
Y	US, A, 4,402,090 (GFELLER ET AL) 30 AUGUST 1983 See column 5, lines 55-58 and figure 4.	1-7,9,11-15,17
Y	US, A, 4,7171,913 (ELGER) 05 JANUARY 1988 See figures 1-4.	9-10,16-17
Y,P	US, A, 4,908,819 (CASADY ET AL) 13 MARCH 1990 See claim 19.	1-7,11-15
Y	US, A, 4,415,065 (SANDSTEDT) 15 NOVEMBER 1983 See column 2, lines 65-69 and column 6, lines 40-68 and column 1,lines 44-48.	1-7,11-15
Y	US, A, 4,727,600 (AVAKIAN) 23 FEBRUARY 1988 See figure 1.	19,23,26,30
Y	US, A, 2,153,709 (BOURNSTEIN) 11 APRIL 1939 See figure 1	20-21,23-25,31, 33,35-36,39-42 45
Y,P	US,A, 4,977,619 (CRIMMINS) 11 DECEMBER 1990 See claim 2	27-29

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
26 MARCH 1991	15 APR 1991
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	Nguyen Ngoc Ho fn LESLIE PASCAL NGUYEN NGOC-HO INTERNATIONAL DIVISION

Form PCT/ISA/210 (second sheet) (May 1986)